THE MECHANISM OF LIFE

" Of philosophy I will say nothing, except that when I saw that it had been cultivated for many ages by the most distinguished men, and that yet there is not a single matter within its sphere which is not still in dispute, and nothing, therefore, which is above doubt, I did not presume to anticipate that my success would be greater in it than that of others; and, further, when I considered the number of conflicting opinions touching a single matter that may be upheld by learned men, while there can be but one true, I reckoned as well-nigh false all that was only probable."—DESCARTES: *The Discourse on Method.*

" When I wrote my paper on the thymus gland, I was very conscientious about the literature on the subject. I found that many memoirs had been written and published, and I looked at them all—or, at least, at all of them that I could obtain. There were many German works, not many French and Italian ones, and a number of English papers. I collated and made abstracts of them, and discussed all the results and conclusions, and, generally, rounded off our knowledge with regard to the matter. Altogether I found afterwards that there were fifty-two memoirs on the development of the gland. My paper only made the number fifty-three !"—*Unpublished Letter from a Young Zoologist.*

THE MECHANISM OF LIFE

IN RELATION TO MODERN PHYSICAL THEORY

BY

JAMES JOHNSTONE, D.Sc.

PROFESSOR OF OCEANOGRAPHY IN THE UNIVERSITY OF LIVERPOOL

LONGMANS, GREEN & CO.

LONDON: EDWARD ARNOLD

1921

Printed in Great Britain.

PREFACE

It is possible that the title of this book may be misleading to some readers, and so an explanation may, very appropriately, form the subject of this introduction. Well, then, by "the mechanism of life" is meant nothing more than the results of a scientific analysis of the activities of living animals. First, we must define what is meant by "scientific method," and this is not at all difficult now that Einstein, Eddington, and the other relativists, have persuaded us to think about what we do when we investigate something "scientifically."

What we do, in that case, is to observe space-time coincidences in a four-dimensional manifold—that is really and actually our procedure, though it seems rather dreadful! It would be very inconvenient, also, to sustain oneself in this plane all the while, and so we proceed to let ourselves down to earth, so to speak. From the space coincidences that we observe (for instance, the coincidences of the top of a column of mercury in a barometer tube with certain marks on the adjoining scale) we infer space measurements, and from the coincidences of the hands of a clock with marks on the dial we infer time measurements. That simplifies the method a good deal.

Then it is only the relations between series of space-time measurements that form the data of science (its differential equations), but that, again, is very trying, and so we assume that there are things in nature. These things are separated from each other, at the same instant of time, by intervals of space, while they are separated from each other, in the same space, by intervals of time. Thus we have something to lean up against and sustain ourselves in this rather difficult process of apprehending nature. The things that we regard as existing apart from each other in space and time are electrons. But just yet that is rather inconvenient, and so we regard our natural things as atoms and molecules in motion in an arbitrary three dimensional space and an arbitrary one-dimensional time.

Thus there are atoms and molecules which exist and move and form configurations—that is, constitute physico-chemical systems in space and time. When we speak about a "mechanism," we mean the motions and configurations of material particles. Already we have gone a long way, *via* inferences, from our "real and actual" observations of the passage of nature, which observations are space-time coincidences; but never mind that: let us stick to our notion of mechanism—systems of material particles and their motions and configurations. The descriptions of such systems by making use of space measurements, and the devising of mathematical relationships between them (the differential equations), are the method of science. What we call "space" may be measured in terms of x and y and z, the old space dimensions, and t the time one; and so the equations that we make involve the four "variables," x, y, z, and t.

That is what physiology does; whatever its particular methods may be, they involve the observations of space-time coincidences —the readings of the pointers, scales, etc., of instruments. It observes systems of material particles (the atoms and molecules making up tissues) in certain configurations, and then, after intervals of time, in other configurations. Sometimes the differences between the configurations can be thrown into mathematical forms, but more often they cannot.

This, therefore, is what is called mechanism, and it is the method of physiology. It is the study of the successive phases of a material energetic configuration or system. Note that it is not necessarily the study of an organism. Usually what is investigated is a part of an organism, or even the dead material of the latter. And in all cases it is the study of the physico-chemical activities of the organism that is the object of physiology. In the very act of investigation these activities are necessarily dissociated from each other, and the result is a number of partial views of the whole organic activity. Of course, all this is indispensable, and so the greater part of this book is really a summary of the main results of physiological science, and is intended to give the reader an attitude (for he must supplement what is said here) in his attempt to understand life.

It would be inconvenient, and even pedantic, to state these results in terms of the fundamental space-time concepts, and so our analyses of the activities of the living organism must continue

to use the familiar ideas of atoms, molecules, colloids, chemical and physical states of equilibrium, energy-transformations, potentials, radiation, and so on. In the light of modern physical theory, however, most of these concepts are derived ones, and if we use them in speculations upon the nature of life, there may be some crudeness in our statements. Thus, quoting a very good modern statement as to the aims of biology *—

1. "Scientific biology is strictly deterministic. It admits the possibility of only one result from a given set of antecedents."

2. "Scientific biology endeavours to explain organic phenomena on the basis of antecedent physical conditions, though admitting that our knowledge of cause and effect is in the last resort empirical, to the extent that much which happens could not have been predicted in advance."

3. "Scientific biology declares that vital phenomena are chemico-physical in the sense that they are the inevitable outcome of the particular material aggregations which we call organisms."

Now whether our knowledge can be regarded as proving the above theses is the subject of the following chapters. We must be very clear as to what is meant by "determinism," "antecedent physical conditions," "cause and effect," and "particular material aggregations." We have really nothing to do with determinism because the concepts that we employ in discussing our results are those of functionality, correlation, and probability. Determinism is a logical category, or perhaps convention, and it is strict only in mathematics, where, since we make the rules, the strictness of result is to be expected. We assume determinism because it is our mental postulate, and also because we find that it works more or less approximately in chemistry and physics, and even in physiology, so that we can construct and use machines and cure some diseases. But it never works out exactly, and our results always have the form $V \pm e$, where V is the value we adopt for something or other as the result of experiment, and e is a "probable error." We never get a unique biological result from a "given set of antecedents": thus the bodily characters of an individual animal may surely be regarded as the result of the characters of its ancestry (which are the "antecedents"; but this individual result is only one of

* F. B. Sumner, *The American Naturalist*, vol. lii., 1919, pp. 193-217; vol. liii., 1919, pp. 338-369

a number of such (the combinations of bodily characters of the brothers and sisters of the individual), and all of these combinations differ from each other though they have the same antecedents. Sometimes we say that the individual results "ought to be" the same if only we could experiment or observe with sufficient accuracy; but in saying so, are we not simply dogmatising?

Further, it is said that "vital phenomena are chemico-physical in the sense that they are the inevitable outcome of the particular material aggregations that we call organisms." But they are not "inevitable," and are they the outcome of "material aggregations"? It is quite certain that it is not material aggregations that our method of science observes in nature, but rather space-time coincidences. We do not know about things, but only about relations—which are differential equations between *dx*, *dy*, *dz*, and *dt*, which symbols are, after all, "ghosts" of space and time. No doubt it is very difficult to think in this way, and one naturally leans up against a mentally constructed world of atoms—mathematics is so tiresome! But when we would speculate about the nature of life and so on, we must not lean up against anything, and our analysis should at least be as penetrating as that of the physicists. On the whole, one prefers the conclusions of some of the latter—our knowledge of the world is a knowledge of form and not of content. We know relations only, and the unknown stuff of the world may just as likely be the stuff of our consciousness as something consisting of electrons.

Anyhow, life is, after all, mainly an affair of organisms acting individually and as entire, undecomposable entities. It is mind, feeling, perception, memory, emotion, pleasure, pain, and so on. To the vast majority of men and women (to say nothing of all the "lower" animals) these states are life, and it would be very stupid not to recognise that in our philosophy. Tropisms and "concatenated reflexes" and colloids and enzymes, and so on, are all very well in their way, and we have to investigate them if we are to get on in the world, and be comfortable, and live long (quite legitimate objects of scientific research); but are these notions anything else than the terms in our description of how the living (or dead) organism cuts up, so to speak? Is not this common sense?

If we do recognise that mind and intuition of living are to count in our speculations, what becomes of determinism (and

prediction, which surely goes with determinism—if we cannot predict, why say that events are determined)? For mind and memory and feeling and perception are certainly not measurable in terms of space and time (despite the Weber-Fechner "psycho-physical law"). So the problems of free-will and necessity and determinism are meaningless when they are considered with reference to the mind, for the very essence of these notions is measurement, and we cannot measure mind.

Such, then, are the lines on which the phenomena of life are discussed in this book, and the reader is asked to take the arguments "on their merits," and without conscious clinging to either mechanism or vitalism.

Vitalism holds that there is something in the living organism which is not present in an inorganic thing. This may be "spirit," or "soul," or perhaps some hitherto unrecognised "biotic energy-form," or some factor which is not energetic in nature, but which confers direction upon the energy-transformations that occur in the living organism. Most people take one or other of these attitudes; thus some may confess to sympathy with those who would "remove organisms from the domain which includes the stars and precious stones," but may not think that mechanism "exhausts the reality of earth and heavens, still less that of the flower in the crannied wall"; others like to think that "the sun and moon and all the little stars are a glorious mechanism." Either feeling is, of course, permissible, provided it does not influence our judgment.

Also, no one can think about these questions without becoming "metaphysical," even if he does not know it. There is no harm in that either, provided that one does it nicely. So I have taken care that anything "transcendental," or otherwise objectionable, has been discreetly relegated to the Appendices.

J. J.

LIVERPOOL,
1921.

CONTENTS

THE MECHANISM OF LIFE

CHAPTER I

ON THE NATURE OF ANIMAL LIFE

The Organism as a Structure.—The student of biology usually begins his studies by dissecting the body of a warm-blooded animal; and, first of all, he notices a division of this into well-marked regions: head and neck, trunk, limbs, and perhaps a tail. Then, taking a knife, he slits the skin over a limb and finds beneath it fleshy masses (the muscles) attached to rigid supports (the bones). He sees that the latter are movable on each other by articulations, or joints, and from his general knowledge of the animal in the living state he recognises that bones and muscles are parts that move in ways that depend on the nature of the articulations. Looking more closely, he sees white, glistening threads beginning in the muscles, joining together and passing into the central parts of the body. These are the nerves. There are also two kinds of bloodvessels: one kind which are stiff and white and apparently empty, and another kind which are rather thicker and softer, and which contain blood. The former are arteries, and the latter veins. All these parts—bones, muscles, nerves, arteries and veins—are wrapped up in a loose kind of material called connective tissue, and this must always be separated in order to disclose the forms of the muscles and other parts, and the ways in which they are joined together.

Then, opening the cavities of the body, he discovers the viscera—that is, the lungs and heart, which occupy the cavity of the thoracic region of the trunk and the stomach, liver, alimentary canal, kidneys, digestive glands, and reproductive organs, all of which are contained in the abdominal cavity. Here, too, attentive study shows the existence of bloodvessels and nerves which ramify among the visceral parts.

Lastly, breaking open the bones of the skull, he finds a white,

soft mass in the cavity of the head. This is the brain, and further examination shows that it is connected, by means of nerves, with the great sense organs of the head—that is, the eyes, ears, nose and tongue—but also with a similar mass of nervous tissue lying inside a tubular cavity in the backbone. This is the spinal cord, or marrow. Looking at it more closely, he finds that the spinal cord gives origin to nerves which can be traced out into the muscles of the trunk and limbs, and also into the skin.

In short, he finds that the animal body is a structure: a series of parts arranged in a definite way.

Structural Differences.—Now, extending his study to other examples of the animal kingdom, he finds other structures which are analogous, or similar in a general way, to that which he has already examined. There are, however, very notable differences. The fore and hind limbs of the mammal are replaced by the wings and legs of the bird, or by the little side fins of the fish. He will find that all backboned animals possess these two pairs of limbs in some form or other, but that they may differ remarkably in structure. Examining the animals below the vertebrates, he will find still greater differences: thus there are about twenty pairs of limbs (or appendages) in a crab, shrimp, or lobster, but many more in a centipede, and such a creature as a starfish has apparently no limbs at all (though one speaks about its radial "arms"), but beneath the body he will find some thousands of mobile parts which serve for locomotion, and are known as the "tube-feet." The viscera also vary very strikingly. Thus there are distensible lungs in the quadrupeds, but these are relatively compact and inelastic in the birds, and attached to them are a number of long "air-sacs." There are no lungs at all in the fishes, but he will find gills there, organs which are apparently wanting in the warm-blooded animals. The heart, again, differs greatly in the various kinds of animals; thus it has four chambers in the mammals and birds, three in the frog and some other amphibians, but only two in the fishes. The eyes are large and well-developed in all backboned animals, but quite different in structure in insects and shellfish, like the crab and lobster; different, again, in the cuttlefish, rudimentary in the snail and in most worms, and wanting altogether in such creatures as the oyster, mussel and cockle.

Thus the student of comparative anatomy finds very great differences of structure in the various groups of animals: differ-

ences so extraordinary that without the key given to us in the hypotheses of evolution it would have been difficult or impossible to compare animal organs one with another.

Now we might spend a lifetime (as many men have done) in studying the anatomy of animals, and yet one would really never have studied the animal at all! It is only when we look at the things that organisms *do* that we are students of life. In spite of the extraordinary differences of structure (as, for instance, between a rabbit and a starfish), there is a remarkable similarity in the *functions* performed by the organs of the body. Limbs, legs and wings, fins, appendages, tube-feet, etc., are the means of locomotion, and they enable the animals possessing them to run or walk, fly, swim, creep, etc. Teeth, claws, horns, spines, stings, poison-glands, etc., are all weapons which are employed to maim, capture, and kill other animals. The alimentary canal and its glands are the organs of nutrition, the means whereby the animal digests and assimilates its food. Lungs and gills are contrivances whereby oxygen is obtained from the atmosphere, or the sea-water, and the heart and blood-vessels are the mechanism by means of which the oxygen, and also the digested foodstuff, are distributed to all parts of the body. Eyes, ears, nose, tongue, feelers, etc., are the apparatus of sensation, and it is by means of these that the animal becomes aware of the changes that occur in its environment.

Add to all these things the multitudinous contrivances by means of which animals reproduce, bear offspring, and nourish and cherish the latter.

Structure and Function.—Evidently, then, structure varies in a remarkable degree, but the things that animal structures or organs do are very much the same in spite of the structural or anatomical differences. Limbs, wings, fins, appendages, etc., are the means whereby the animal moves, distributes itself over the world, seeks its prey, or avoids its enemies; and teeth, claws, etc., are its weapons—the means of defence and aggression. These organs, with the alimentary canal and its glands, enable the organism to catch and kill and digest its food. All modes of reproduction, whether sexual or asexual or parthenogenetic, have the same purpose and effect—that of the perpetuation of the race. Obviously, then, it is not structure that is the essence of animality, for structure is only the means to various ends.

An animal is—

> Something that tends to preserve its own individual existence;
> that nourishes itself; and
> that reproduces itself.

Self-preservation, nutrition, and reproduction are, therefore, the characteristics or the essential marks of life. We may call them the primary instincts, tendencies, or impulses of animality.

If we knew only the structure of animals, we might be able to find what were the functions or things done by those structures, but the history of comparative anatomy gives us many instances of our failure to do this. And, conversely, a detailed knowledge of the things that an animal can do does not always enable us to discover the kind of structure or mechanism that is at work. In a sense it is all wrong to speak about an animal as a structure, or even as a *thing*. It is "something happening."

And yet we are about to write several chapters concerning the "animal mechanism," "organs," "parts," etc., and so we must point out that it is not in any spirit of paradox that we take the dynamic view of animality suggested above. "If," said Lord Kelvin, "I can make a mechanical model, I comprehend." This is our way of investigating, not only life, but everything of which we can become cognisant. The human mind is essentially constructive, and it tries to act upon everything that is outside itself; that the animal must act in this way is the reason that there is a mind at all. When we look at a mechanism and try to understand how it works, we either actually take it to pieces or we do so in imagination—we make an analysis of an activity of some kind. We cannot describe a marine engine without considering the cylinders, cranks, crank shaft, reversing gear, etc., even though we know quite well that all these parts exist, as parts, only in the case of an engine that does not go. When we think of, or see, the mechanism at work there are no parts, and, of course, there are none after the engineer "assembles" them. And so our conception of the organs and parts of the animal body is only our analysis of the means of life. In a way they are what Lord Kelvin called his mechanical models, and their usefulness is that they enable us to comprehend and investigate. But in the normal, living animal the parts are integrated, and their activity is an indivisible one.

Think about it carefully, and we find that the normal, healthy man or woman has no intuitive knowledge of the separate activities of the parts of the body. Most of us are (or ought to be) quite unconscious that we possess stomach and liver and lungs, and so on, for all these organs are acting together and form a harmony. We assume that these parts are in us because of our knowledge of the structure of the bodies of other animals, but, lacking that knowledge, it is unlikely that we should be able to make an analysis of the activities of our own bodies. It requires some effort of concentration to convince a healthy man that he possesses a liver and stomach. It is true that he would be periodically conscious of a "feeling" of hunger, but that would be something quite different from the empirically acquired knowledge that his stomach was empty.

Integration of Activities.—The healthy living animal is one and indivisible, and the more deeply we study physiology the more clearly do we see that no organ functions by itself and for itself—at least, not in the healthy animal. Let us illustrate this by considering the process of respiration. Concentrating our attention on this phase or aspect of our living activity, we find that the chest wall rises and the diaphragm sinks, and so the cavity of the chest is enlarged. But the lungs fill this cavity; they are distensible, and so air rushes into them to fill up the extra space produced by the act of inspiration. Next, look at the composition of the air inhaled and exhaled; it is different in respect of the percentage of oxygen that it contains, and so we find, on further investigation, that oxygen is taken into the blood-stream *via* the lungs, and is then carried all over the body. At the same time nutritive material is being taken by the blood from the alimentary canal, and is being distributed over the body, and is built up into the substance of the tissues, where it meets with the oxygen that comes from the process of respiration and is oxidised. This oxidation sets free energy, which is then transformed into the mechanical work done, and the heat generated by the muscles. But the muscles themselves are being employed to activate the respiratory machinery that supplies them with the indispensable oxygen.

Now, imagine that the percentage of oxygen in the air is becoming much less than is normal, and that the percentage of carbonic acid gas is increasing; at once everything changes. The respirations become quicker and deeper, and the heart's rate

of beat increases. Other muscles of the chest and abdomen, which before were inactive, now become employed to increase the capacity of the thorax, and so to draw more air into the lungs. The shoulders and arms are used as the air becomes more and more deficient in oxygen and richer in CO_2, and bending movements of the body occur so as to increase the ventilation of the lungs. Finally, in the distress of asphyxiation there is hardly a muscle in the whole body that is not pressed into the service of supplying this absolutely vital oxygen to the blood.

That means that most of the organs of the animal body can act vicariously. When one kidney or lung is diseased, the other responds to the strain on the system, becomes bigger, and takes over some of the work that its partner formerly did. The lungs, skin, and kidneys all excrete water, and if one of the three is diseased and cannot properly function, the others increase their activities. When there is local infection by bacteria, the phagocytes of the blood, which are, normally, fairly evenly distributed throughout the body, now crowd to the injured place and seek to destroy the intrusive organisms. And so on; it is one for all, and all for one. In the healthy animal the activity of any one organ is regulated by those of all the others to produce a harmony of action in which there are really no distinct parts.

Inco-Ordination of Activities.—But there is also disease and pain, and we must enquire into the meaning of these conditions. In the healthy animal every part of the body is in nervous connection with the brain and spinal cord, and a multitude of impulses are continually streaming from the tissues to the central nervous system. Generally we do not attempt to make an analysis of this undeveloped sensation, and it blends to produce a vague but satisfactory feeling of normality, and that is (as we shall see later) because all these impulses entering the centres from the periphery are answered or receive appropriate responses. They are verified, co-ordinated, integrated. If they are not, if there are insistent impulses from the tissues that do not end in suitable responses, there is pain. The vague feeling that dinner-time is approaching passes insensibly into hunger—a stimulus which ought to find its response in an act of eating. If it does not, if the stimulus remains unanswered, we recognise it as pain.

Disease is more than this; it is a disharmony, a disturbance of the general, unified functioning of the body—the indication of truly partial activity. If there is individualised, uncontrolled

over-production of hydrochloric acid by the gastric glands of the stomach we have acidity, and if there is under-production of pepsin we have dyspepsia. When there is over-production of secretion by the thyroid gland there is exophthalmic goitre, and when the secretion is deficient there arises the condition of idiocy called cretinism. If the secretion from the pituitary gland is produced in excess there is malformation of the bones of the face, and when there are abnormalities in the functioning of the pineal gland (see p. 99) in young people there are consequent aberrations in sexual development. When there is uncontrolled proliferation of the cells of the mammary glands in women there arises the most sinister of all diseases—cancer.

And so on. The result of operative interference with the animal body and the effects of disease are truly to set up partial activity. Then we deal with a disharmonious complex of organs, whereas the normal healthy animal is a harmony, an "unity in multiplicity," an integration of activities. The diseased man is a little less than animal, for something is wanting, and the dead body is a structure—really an assemblage of inactive parts, and not at all an animal. The heart taken from a tortoise will live several days and continue to beat, but it is not an animal, and in studying it we are making an analysis and are not observing a living organism.

We have insisted on the conception of the animal as an integration of activities, and more and more this is forced upon us, as we shall see in the study of the central nervous system. Now it is interesting to compare the organism with the modern State; the comparison has often been made, far more often in a spirit of sentiment or as the support for some propagandist object than in the light of an accurate knowledge of biology. We intend this book for the general student of social science, as well as for those who seek culture, and so we make no apology for a reference to the comparison between the State and the organism.

The Organism and the State.—Of course, the modern State is not an organism, not even by analogy. The animal body is a complex of cells, even as a polity is a complex of men and women; but the cells of the body are structurally connected, while the units of a population are truly individuals, discrete and physiologically distinct from each other. Now let us neglect such a difference between the two complexes—the organic and the social ones—and ask the question, Does the activity of the

modern State approximate to the complete integration of activities exhibited by the healthy animal ?

Obviously it does not. No State so far developed has ever exhibited such complete socialisation of activity as does the normal organism. It is doubtful if in a modern society, even in the most homogeneous one known to us, men and women are all of the same kind! The results of the study of "genetics" or "eugenics" indicate that they are not. There are "strains" or "races," germinal differences that are persistent. "Stock" is more important than environment or training. "Nature is stronger than nurture." The modern community is not one, but many; and it does not possess organic unity. There were "two nations" in England, said Disraeli, "the rich and the poor." There are many, implies genetics, and obviously the interests of these racially different stocks are not the same.

That is to say, there is a "class structure." There is a "ruling class," a "bourgeoisie," and a "proletariat." There are idlers and workers, consumers and producers. There is a class consciousness, the social analogue to what we call pain in the animal body, for the harmonious body politic would only be vaguely conscious of a feeling of normality if all its activities blended, and if all stimuli from its periphery met with appropriate responses. Obviously there is individualistic activity and resentment at attempts towards integration (which is, of course, the tendency of socialistic propaganda). There are opposed interests because of this individualism and the tendency towards "class war."

In short, if the body politic is an organism it is at the same time a diseased organism, and the analogy with the biological entity points to the way in which the cure is to be obtained.

CHAPTER II

THE SENSORI-MOTOR SYSTEM

We must not attempt to set up any absolute distinctions between plant and animal organisms, or even between one group of animals and another one. Birds, for instance, appear to be quite different in regard to their structure and habits from reptiles, but when one considers the extinct species known to us by their fossils the differences that we see in the living animals are largely obliterated. Typical plants, such as an ash tree or a toadstool, differ greatly from typical animals such as a fish or a spider, but there is no absolute difference between some of the microscopic algæ (which are plants) and some of the microscopic organisms called infusoria (which are animals). That which we must regard as characteristic of plants on the one hand, and animals on the other, are the *tendencies* that they display.

Thus the typical plant tends to be a rooted, sedentary organism. As a very general rule its movements are those of growth, and these movements are orientated. The roots tend to grow downwards in the line and towards the direction of the earth's gravitative force, and the stems tend to grow upwards towards the direction from which light mainly comes. Other kinds of movements occur, such as the turning of tendrils round fixed supports, the opening and closing of some flowers, and the motions by which the pitcher plant traps insects, but these are not very common; they are not typical, and when we analyse them we can place them in the same category as the movements called tropisms (those of the root and green stems).

Animals, on the other hand, tend to be freely mobile. There are many exceptions, of course; thus the zoophytes, corals, sea anemones, etc., are fixed, sedentary organisms, and so also are many kinds of parasites (fish lice and tapeworms, for instances). But the great majority of animals tend to move about; they are locomotory, and their movements exhibit a certain general character which is fairly well described by the term "animal behaviour" in the popular significance of those words. The motions included in such a term are often deliberate and chosen

—that is, the animal behaves as if it knew very well what it wanted to do and how to do it—but often there is hesitation, and even what we should call caprice, so that we cannot always predict what the creature is going to do. Often, again, an animal appears to behave precisely like ourselves when we " will " to do something—that is, it appears to act spontaneously.

Now motion in itself is not something that is distinctive of organisms, for the particles of all substances are in a state of continual movement (except at absolute zero of temperature), but this kind of motion is either a fixed, vibratory, or oscillatory one (the regular oscillations or revolutions of the electrons or atoms, for instance); or it is a random movement (as are the molecules of a gas, or the finely divided particles of some substance in suspension in a liquid); or it is such movements as those of the satellites and planets in a solar system, absolutely predictable; or, again, it may be the apparently random movements of the " fixed " stars in what has been called their " helter-skelter " flight through space.

The Meaning of Organic Movement.—Organic movements are, however, different in their tendencies from those that we have just mentioned, though it is not easy to put this difference succinctly and accurately. Perhaps one may say that the movements of plants and animals are, in the first place, growth movements determined by internal causes, and, secondly, they are adaptive movements—that is, useful and purposeful responses on the part of the organism to changes occurring outside itself. Here " useful " and " purposeful " mean that the result of the motion is something to the advantage of the organism. These remarks, it will be noted, apply to both plants and animals. In the case of the former the responses tend to be inevitable responses to simple, natural stimuli, and they can usually be predicted, while in the latter case they are responses to individualised stimuli; they are partly determined by experience, and they cannot usually be predicted. We must not linger on these distinctions here, for we shall return to them in a later chapter.

Animals, then, tend to exhibit a great variety of adaptive movements, and it is by seeing these that we say that we are looking at an animal; for, obviously, the structure of the latter is almost entirely the means by which the movements can be made. We must now consider what is the nature of the latter.

Mobility Patterns. — Animal movements, then, fall into generalised and individualised patterns: first those of the body as a whole (locomotion), and then those of the parts of the body. We shall take the more complex patterns first, as these will be the more familiar to the reader. There are the walking, running, and leaping of quadrupeds; the walking and running of flightless birds (which are bipedal movements); and the leaping movements of arboreal quadrupeds, such as monkeys. There is the flight of birds and insects (two rather different types), the flight of bats and squirrels, and the incipient flying movements of some fishes. Next, take the movements of locomotion in water: the swimming of typical fishes, seals, and whales; the swimming of a dog or horse; and the swimming and diving movements of birds. Very different from these are the swimming of crustaceans, such as copepods; the bizarre leaping movements of a lobster or scallop; or the swimming of a cuttlefish or squid. Burrowing, as in the cases of moles, earthworms, ants, and fossorial wasps, is an entirely different kind of movement, and so is the creeping of a slug or a centipede. The extremely limited locomotion of a mussel or cockle is different again, and still more so the creeping of a starfish. Among microscopic animals we have the peculiar movements carried out by cilia, as in the cases of flagellate organisms, infusoria, rotifers, or even spermatozoa.

All these are categories (generalised patterns); thus the same kinds of locomotory movements are made by all typical fishes, but the swimming of a herring or mackerel shows minor differences from that of a sole or plaice, and so we have subcategories. Again, the patterns may be specific ones; thus the movements of a panther are rather different from those of a bear. Or they may be subspecific (in the zoological sense); thus the walk of an Airedale differs from that of a fox terrier. And, finally, they may be individual; thus the "carriage" of a man or woman that one knows well is characteristic of that person, and no one else.

So also with postures and attitudes, and with the movements of the limbs and other parts of the body that are used in defence, aggression, etc. Thus there are biting, slashing, cutting, grinding, and gnawing movements of jaws and teeth; clawing movements like those of a cat or a bear; goring and tossing and butting actions of horns; the use of spines, as in a sting ray; the lateral swinging movements of the tail, as in a crocodile; crushing and

cutting movements of the mandible, and pincers in crabs and lobsters; piercing and sucking by the proboscis of such an insect as a mosquito; stinging by bees and wasps, aided by the injection of poisons; the gripping and sucking action of the cuttlefish, squid, or starfish; snaring movements involving constructive devices, as in the web of a spider, and so on. All these are just as characteristic of groups of animals as are the locomotory patterns.

Such mobility patterns go roughly side by side with structure patterns; thus, quadrupedal locomotion involves the use of fore and hind limbs; flight that of one or two pairs of wings; swimming means that there are fins (or other movable and fixed hydroplanes), or cilia, or flagella; creeping requires a number of serially arranged appendages (like the " legs " of a centipede, or the setæ of a worm), and so on. But the parallelism between structure and mobility patterns is not always complete; thus the dorsal fin of a fish may be a vertical rudder, a poison organ, or a lure; certain bones in the head of a vertebrate animal may be parts of the skeleton of the jaws (in fishes), or the little " auditory ossicles " of the internal ear (in mammals); the same (historical) limb may be a paddle (in a seal), a wing (in birds), or an arm and hand (in man). Knowing what the structure is does not always mean that we can deduce the function, and *vice versa.*

And we are mainly interested in either the structure or the function of the structure, according to our point of view. The former is our main object of study from an historical aspect, as when the same structure gradually became modified; thus a seal is a modified carnivore which has adopted an aquatic habit, in the course of which a typical quadrupedal limb became modified in structure to serve as a paddle. But here we are concerned with an animal mechanism, and so we regard paddles, fins, and limbs as three variants of a generalised locomotory pattern.

That means that it is the animal as a whole that we are studying: its modes of movement that enable it to distribute itself, to find shelter, to escape from its enemies, to capture and kill the organisms which serve as its food—in general, its behaviour and the ways in which this is expressed. And so we must study the structure of the mobile animal parts as a means of our analysis of living activity.

The Sensori-Motor System.

The organs of mobility include the **skeleton,** which is a system of rigid and jointed bones to which the *muscles* are attached; the **sense organs,** by means of which the animal comes into relation with its environment; and the **nervous** system, which is the link between the sense organs and the muscles. The animal is placed in the midst of an environment which continually changes, or it moves about from place to place, and therefore the conditions under which it lives are variable. It must find shelter, and the nature of this will vary with the climate and seasons; it must find food, and the nature and abundance of this also changes; and it must avoid its natural enemies. Therefore it must become aware of the events that proceed outside itself, and that is why it sees, hears, smells, and "feels." The events that occur in the environment affect or stimulate its sense organs; but that is not enough, for the stimuli must result in actions of some kind. Now we can imagine the stimulation of an organ of sense to produce two main kinds of response: First, the response may be mechanical, constant, and predictable, just such a response that would occur in a model that we could easily construct. In an artificial animal or automaton we press a spring, and the machine begins to walk or to lift a limb, or rolls its eyes, but the result of pressing the spring will always be the same. Tropisms—that is, the kind of responses to which we referred on p. 9, and which we shall consider in greater detail in Chapter VIII.—tend to be responses of this nature, and a large number of the habitual actions performed by animals belong to such a category of relatively fixed, mechanical movements. Secondly, the responses may be adaptive—that is, the thing that happens when a sense organ is stimulated depends on the circumstances of the moment and on the experience of the animal. Thus, a man walking along the street may pass a stranger without doing more than look casually at the latter. If, however, the same person subsequently becomes known to him he may thereafter nod, or bow, or stop and speak. Yet the physical stimulus of the organ of sense is the same in the two cases, and the difference of the response depends upon the intervention of the cerebral nervous system.

With these preliminary remarks we may now consider the physical apparatus of movement.

The Skeleton.—The skeleton consists of a series of hard, rigid parts to which the muscles are attached in various ways; thus the chassis of a motor-car is, in a way, the skeleton of the mechanism. The skeleton is also the mobile carrier of bodily weapons, such as the teeth or claws, and a mechanical analogue to it in this second aspect is the jib and scoop of a steam digging machine, or the carrier of the buckets of a dredger. Not all animals possess skeletons, but in those which have soft bodies there is always a rather small limit of size, and most of such organisms live in water, which itself acts as the support for the soft body parts.

The animal skeleton varies to an enormous extent in its form, and sometimes it is very simple. Thus the skeleton of a mussel or oyster is a shell consisting of two valves connected together by a kind of hinge, while that of a man consists of a great number of bones jointed or articulated together in many different ways. Upon the nature of the parts of the skeleton and the shapes of the joints or articulations depend the kinds of movements that may be carried out. Thus the skeleton of the oyster is very simple, and so also is the nature of the only movement of the body, as a whole, which this animal can make. One large muscle is attached to the two valves as indicated in the figure, and when this contracts it pulls the valves together so that the shell remains closed. When it relaxes, the spring or elastic ligament presses the valves apart, and so the shell opens. These opening and closing movements are practically the only ones that the oyster can perform. Now compare with this simple mechanism the very complex one of the vertebrate body as we are about to describe it.

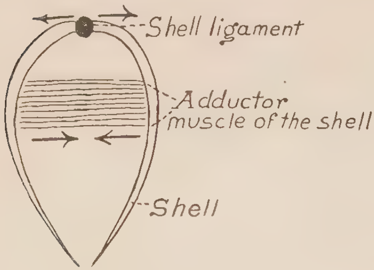

FIG. 1.—A TRANSVERSE SECTION THROUGH AN OYSTER.

Sometimes the skeleton of an animal has no function in movement, but is merely the rigid, or semi-rigid, support of the soft parts; thus the common bath sponge is the horny skeleton of an animal, and supports the fleshy tissues (which have been rotted away in the process of preparing the sponge). This flesh is

arranged round a complicated system of canals through which the sea-water circulates, and the larger of these canals would collapse by the weight of the flesh if they were not kept open by the horny fibres embedded in the latter. There is no locomotion at all here, and the only mobile parts are the vibratory hairs which cause the circulation of water through the canal system. Such an animal as the jelly fish (or medusa) has no skeleton, but it floats suspended in the sea-water, which thus supports the soft, fleshy body. The latter has the shape of a bell, by the expansions and contractions of which water is taken into the cavity and then ejected, and so the medusa slowly moves about. There is no skeleton in a common garden slug, and when locomotion occurs the front part of the broad, fleshy " foot " adheres to the ground, while the latter part becomes detached and is drawn forward and adheres. The front part is then detached, pushed forward, and again adheres, and so on. The earthworm has no skeleton, but the body is provided with muscles which act so that it can be stretched out or shortened. Along the sides there are little projecting bristles, which can be turned forwards or backwards. When the worm burrows, the bristles on the front part of the body are bent backwards and inserted into the soil, and then the hinder bristles are bent backwards also, and that part of the body contracts and is drawn forwards. The worm then bores into the ground in front of it, swallowing the soil, and stretches out the front part of its body, and gets a new grip by its bristles, and so on.

In all insects, spiders, crustacea, etc., the skeleton is an external one, consisting of a hard, horny, or limy cuticle. This acts as the support for the muscles. The body and limbs are jointed, or articulated, and the muscles move these parts on each other in ways that are analogous to those which we are about to describe in the case of the vertebrate animal. Such an exoskeleton would be very heavy if the animal were to attain a large size, and it necessarily prevents growth, which can only occur during the periods when the animal " moults," or casts its shell. That period is one of danger for the crustacean, and so it happens that these animals never have attained to a great size. When the skeleton is an internal one, as it is in all vertebrates, it is mechanically a more perfect structure, and so some of the species in which this kind of skeleton has occurred have evolved to extraordinary sizes, as in the extinct dinosaurs of the Mesozoic

period. But with the increase in mass of the body there occur certain mechanical disabilities, and so we must regard the huge reptiles of past geological times as some of Nature's unsuccessful experiments.

Now we may turn to the skeleton of the present-day vertebrate animals, and here we find the most perfect mechanism so far evolved.

The Axial Skeleton.—The whole structure is built up round an axis, which is the vertebral column, or backbone. This consists of a series of vertebræ, or bony discs, which are attached to each other by means of muscles and ligaments, and they are usually kept in place by little bony projections that articulate with each other. In man there are pads of gristle between the adjacent vertebræ, and the latter have a certain amount of play on each other, so that the whole column can bend sideways and from back to front. In some fishes, however, the latter is practically one bone; in birds only the vertebræ of the neck are movable on each other ; and in snakes the separate bones can move only in the horizontal plane, because of little interlocking side pieces. In front the vertebral column carries the skull, and behind it is often prolonged backwards to form the tail.

The skull consists of two series of parts, the bones of the cranium and those of the face and jaws. The cranium is essentially a bony box containing the brain and the great sense organs, eyes, auditory and olfactory organs. Added to it are the bones of the upper jaw (which are immovable on the skull in man) and the lower jaw, which articulates with the skull by means of a hinge-joint (but, nevertheless, allows of a certain amount of side-to-side movement). The whole skull is attached to the first (atlas) vertebra by a hinge-joint, so that it can move up and down in a vertical plane, and the atlas is attached to the second (axis) vertebra by a peg-and-socket joint, so that the skull can be rotated through a certain angle in the horizontal plane. The neck vertebræ can bend on each other from side to side, and thus the skull has limited freedom of movement in the three directions of space.

The ribs are imperfect hoops of bone which are articulated to the backbone behind. Some of them (the upper ones) are also articulated in front to the breast-bone, and thus the whole series act as an outer protection for the organs of the thoracic cavity—

the lungs and heart. They can be raised up by muscles, and as they are inclined downwards the upward movement enlarges the diameter of the thorax. This is the mechanism of respiration.

The Limb Girdles.—The two pairs of limbs, which are characteristic (as fins, paddles, legs and wings, fore and hind limbs, arms and legs) of all vertebrates, are not attached directly to the backbone, but to the two limb girdles. Each of the latter is a kind of hoop attached to the column. The shoulder girdle consists of the two collar-bones, which are attached in front to the breast-bone and behind to the shoulder-blades. The latter are not attached to the column, but are moored, so to speak, in the muscles of the back. The skeletons of the fore-limbs are attached to the shoulder-blades.

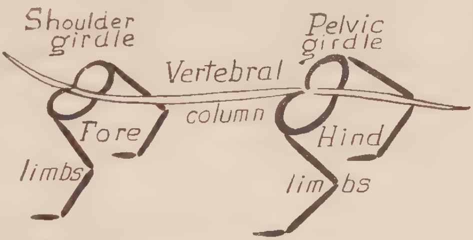

Fig. 2.—Diagram of the Vertebral Column, Limb Girdles, and Limbs in a Backboned Animal.

The pelvic girdle also consists of several bones, and in man these are fused together to form the two hip-bones, which are immovably attached to the column behind, and are joined together in front at the pubis. The skeletons of the hind-limbs are jointed into the pelvic bones, but the latter, together, also act as a kind of basin-shaped support for the lower bowel, the urinary bladder, and the reproductive organs.

Note that the articulation of the limbs with the limb girdles means that the former are set well out from the axis of the body, so that the feet rest on the ground on as wide a base as possible.

The Limb Skeleton.—All the higher animals—that is, the vertebrates, the crustacea (such as the lobster, crab, or prawn), the insects and spiders—possess true limbs, which are organs of locomotion, and are also bodily weapons. The nature of these limbs is, of course, very different in the various groups of higher animals, but in all those that we have mentioned they are jointed appendages of the body, freely movable on the latter, and as a rule furnished with weapons. The limb may be a walking leg (as in the case of the fore and hind legs of most quadrupeds), a fin (as in the case of a fish), a paddle (in seals, dolphin, and

whales), a wing (in birds or insects), a "swimmeret" or paddle-like limb (as in many crustacea), a mobile weapon or tool furnished with claws and cutting organs (as in the case of the fore-limbs of a cat, the large chelæ, or claw limbs of a crab or lobster, or the arms and hand of a man), and so on. Sometimes its structure and degrees of freedom of movement are relatively simple (as in the side fin of the ordinary fish), but in general the limb is a freely movable appendage of relatively complex structure.

The reader may easily verify all that we are about to say by looking at a human skeleton in a museum, and by observing the modes of motion of the parts of his own body. The fore-limb, or arm, then, contains a skeleton that consists of a number of bones connected together in various ways. The bone of the upper arm (the humerus) articulates with the shoulder-blade by a ball-and-socket joint, so that it is freely movable in every direction, and the shoulder-blade itself can be moved (as in "shrugging"), so that the arm has thus additional freedom. The skeleton of the forearm consists of two bones (the radius and ulna), and the latter is articulated to the humerus by a hinge-joint, so that the forearm can be bent on the upper, or extended into the same straight line with the latter, giving 1 degree of freedom of movement.

The radius, however, has a peculiar twisting movement on the ulna, and as the wrist and hand are articulated with it they can be turned round through a half-circle, the elbow-joint remaining immovable. Thus the hand can be turned palm up (supinated) or palm down (pronated). The hand itself is capable of 3 degrees of movement—that is, it can be turned in each of the three directions of space. There are eight wrist bones arranged in two rows, all articulating with each other, one row being jointed with the radius and the other with the long bones of the hand. Thus the hand, as a whole, can move up and down and from side to side on the wrist, so that it has 3 degrees of freedom. Each of its bones, the metacarpals, articulates with the bone of a finger—that is to say, with the first, or proximal phalanx, which articulates with the middle one, which finally articulates with the terminal phalanx (the one that carries the claw, or nail). The articulations between the terminal and middle phalanges and the middle and proximal ones are hinge-joints, so that the fingers can only bend on each other in one plane; but the articulation between the proximal phalanx and

its corresponding metacarpal is, to some extent, an universal joint. Thus the thumb can be bent in the same way as the other digits, but it can also be rotated or swung round in the same way that the whole arm can. The first finger has the same kind of motion, but less of it, so to speak, and so also with the others.

The hind-limb of a quadrupedal animal, or the leg of a man, is built on the same plan, and there may be very little difference between the two limbs (as in a chimpanzee, for instance) with regard to the degrees of mobility of the parts. In man, however, the freedom of movement of the hind-limb is restricted, first by

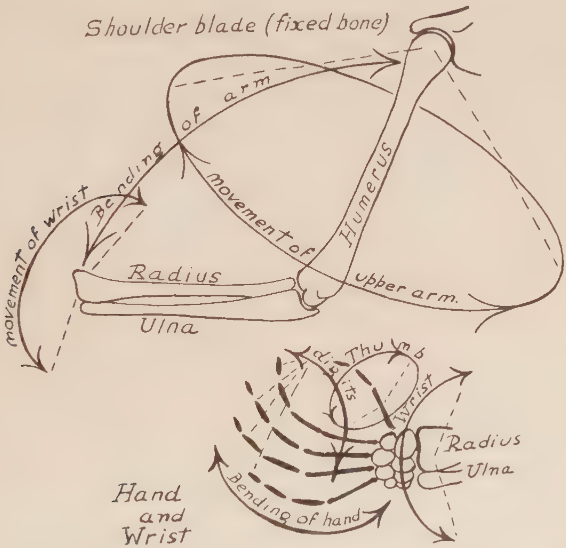

FIG. 3.—MOVEMENTS OF THE BONES OF THE FORE-LIMBS.

the rigid attachment of the pelvis to the vertebral column, and second by the rigidity of the bones of the ankle relatively to those of the wrist.

Such an analysis of the skeleton as we have just indicated (and which can easily be made more precise by the reader himself) shows that the degree of mobility of any part of the body of the higher animal is determined in general by the configuration of the skeleton, and particularly by the shapes of the joints. The latter make it possible for one bone to move on another in one or more ways; thus we have the hinge-joints between the skull and the atlas, the peg-and-socket joints between the atlas and the axis,

the ball-and-socket joints between humerus and scapula, and femur and pelvis, and so on. There is always a checking action of some kind which restricts the extent to which one segment of the skeleton can move on another; thus the movement of the head is checked by muscles (and the relaxation of these when a man goes to sleep causes the head to drop, or fall to one side); the olecranon process (or "funny bone") in the elbow checks the movement when the whole arm comes straight; the patella (or knee-cap) has the same function with regard to the movement of the lower leg on the thigh, and the slipping aside of the patella is the cause of the knee "going out of joint." In other cases the movement is checked by tendons, or ligaments (as in the case of the separate vertebræ).

The Motor Organs.—Now clothe the skeleton with muscles, which are so arranged as to pull on the bones in the ways that the latter are free to move because of the nature of the joints. This arrangement of muscle and bone is the subject matter of anatomy, and it can be treated in enormous detail; but the reader will easily see that, from a mechanical point of view, it is all very simple. We have, in fact, systems of levers, with the various powers: thus

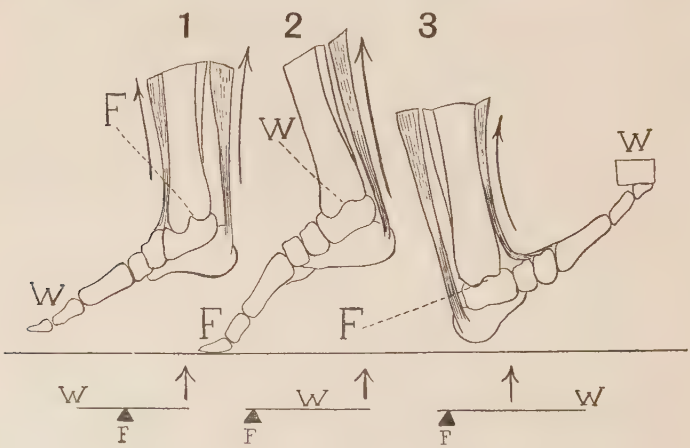

FIG. 4.—THE VARIOUS LEVER MOVEMENTS OF THE FOOT.

Here 1 is a lever of the first order, 2 of the second, and 3 of the third order, and, with various modifications, these are typical of the mechanisms of movement of the parts of the limbs and body.

One example may be given here, that of the bending of the forearm on the upper arm. Four bones are included in this mechanism—the scapula, humerus, radius, and ulna. When we consider only the movement of the forearm on the upper by the elbow-joint, the scapula and humerus are the fixed, and the radio-ulna (considered now as one segment) is the movable part.

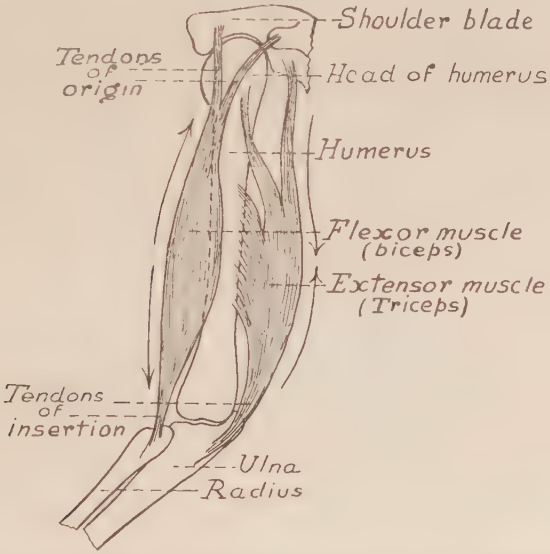

FIG. 5.—DIAGRAM OF THE MUSCLES THAT MOVE THE FOREARM.

Two muscles, we see, are necessary for the movement—the biceps, which is the bending (or flexor) muscle, and the triceps, which is the straightening (or extensor) one. In each case the muscle consists of the tendons of origin (those which are attached to the fixed bone), the belly or contractile part, and the tendons of insertion (which are attached to the movable bone). When the radio-ulna is to be bent, or flexed, on the upper arm the biceps contracts, or shortens (that is, it becomes thicker and shorter), and simultaneously the triceps relaxes, or lengthens (that is, it becomes thinner and longer). By the pull of the tendon of insertion of the biceps the radio-ulna is bent on the upper arm, and by the pull of the tendon of insertion of the triceps it is drawn back again into a straight line with the humerus. It is important to note that the two muscles are antagonistic ones, and that the flexion of one of them is always associated with the

extension of the other. Extension is not merely a passive relaxation, but is the result of a nervous impulse just as much as is contraction.

Note also that the humerus and scapula are fixed bones with regard to the flexion and extension of the forearm, but the humerus is itself a movable part, and the fixed points to which its muscles are attached are in the scapula. The latter is also movable, and then the fixed bones are the vertebra and ribs. The hand is a movable part, and the fixed bone to which its muscles are attached is the radio-ulna. Thus "fixed" and "movable" bones are relative to the parts that are to be moved. The reader must also note that the movement of any part of a limb is never so simple as we have indicated, for several pairs of antagonistic muscles are generally in action at the same time.

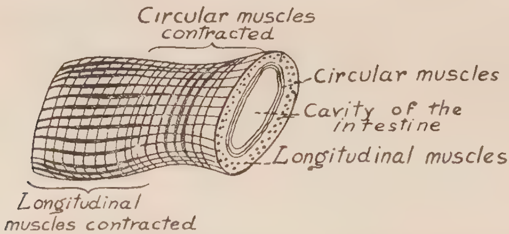

FIG. 6.—DIAGRAM OF THE MUSCLES OF THE INTESTINAL WALL.

Non-Skeletal Mechanisms.—There are many movable parts in the body for which there are no skeletal supports. Thus the heart consists of a very complicated series of muscle bundles that contract and expand automatically. Simpler cases are those of the intestine and bloodvessels. In the former we have two series of muscles, one which is made up of bundles of fibres running circularly in the wall of the bowel, and the other being made up of fibres that run lengthways. When the former contract the diameter of the intestine is decreased, and when they relax and the longitudinal muscles contract the length of a segment of the bowel is decreased and the diameter is correspondingly increased. In this way waves of contraction of calibre of the intestine are set up, and these propel the food contents from place to place. The mechanism of contraction of an artery is very similar, except that the longitudinal muscles are not present. The wall of the artery is elastic, and when the circular muscles contract the calibre is diminished, but when they relax the elasticity of the wall, and

the pressure of the blood within, cause the vessel to regain its former calibre.

There are other special mechanisms of this kind; thus the actions of closing and opening the eyes involve the contractions and relaxations of two antagonistic muscles which are present in the eyelids. One of these, the closing set, consists of fibres that form a kind of ring in the upper and lower lids. When these contract, the opening between the latter is diminished, or obliterated. The closing muscle consists of fibres which originate in the sheath of the optic nerve, and which are inserted into the cartilage of the upper lid; when they contract the latter is raised, the ring-like closing muscle then becoming relaxed.

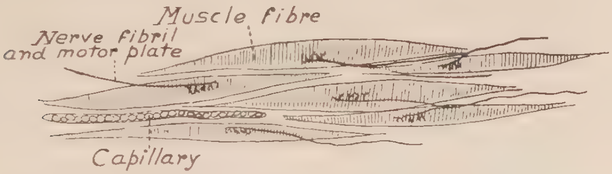

FIG. 7.—MUSCULAR TISSUE. HIGHLY MAGNIFIED.

The Minute Structure of Muscle.—Just a word about this. Examination of a piece of muscle beneath the microscope shows that it is composed of a very great number of minute fibres. Each of the latter is about $1\frac{1}{2}$ inches in length, and it tapers away to a fine point at each end. Numbers of fibres are bound together by connective tissue to form muscle slips, which are similarly joined up to form bundles which constitute the muscle itself. A nerve fibre terminates in each muscle fibre, as shown in Fig. 7. In addition, arteries carry blood to the muscle, where it is distributed through the capillaries and from which it is carried away by the veins. The muscle fibres act at the same time, all of them thickening or contracting when the muscle pulls on its movable bone, or simultaneously lengthening when the muscle relaxes.

As the figure shows, the fibres are cross-striped, and this striation is, in some way, part of the mechanism of contraction and relaxation. But the muscle fibres that are present in the intestinal or arterial wall are not cross-striped. This presence or absence of striation goes along with a difference in the control over the muscular actions; in most of the cases where the activity of a muscle is controlled by the will (voluntary muscles) the fibres

are striated, while in those over which we have no control (the muscles of the heart, alimentary canal, and bloodvessels chiefly—the involuntary muscles) the fibres are "plain," or non-striated, or are otherwise different from the ordinary striated fibres.

The Sensory Mechanisms.

So much for the apparatus of mobility. The reader can easily supplement the above very general summary from the textbooks on physiology. Next we have to consider how this apparatus is set in motion, and that leads us to the study of sensation. There are certain mechanisms, mainly those of the heart and respiratory organs, which are automatic—that is, they work in the absence of any external cause (though their rate of working is affected by outer events)—but in most of the muscular mechanisms of body and limbs a stimulus is necessary in order that they may be set in motion—that is, something analogous to the pressing of the spring in our imagined model must occur.

Sensation, then, is the preliminary to movement, and here we mean by "sensation" only the physical and chemical events that occur in the organs of sense and in the nerves and brain, and not any affection of consciousness; when the latter occurs we have to do with *perception*, and this we consider later. Things that happen in the environment, then, affect the organs of sense: the movements of material bodies are known to us by vision, for the light reflected from those things enters the eyeballs and forms a picture on the retina, which is the essential organ of vision; vibrations in the atmosphere are set up by other material movements outside ourselves, and these vibrations are received by the auditory organs; the particles of chemical substances floating in the air are drawn into the nose or mouth, and so affect the olfactory and gustatory organs; while contact of material substances with the skin similarly affects the nerves that terminate there. These sensations we call sight, hearing, smell, taste, and touch.

Exteroceptive and Proprioceptive Sensation.—Changes that occur outside the body thus affect the organs of sense, or, as we shall call the latter, the **receptors.** The eyes and auditory organs are therefore exteroceptive organs, or distance receptors, for they are affected by events that may happen at considerable

distances away from the body. The olfactory, gustatory, and touch organs are near receptors, for they can only be affected by substances that actually come into contact with the body. Our sensation of temperature may be a near affect (as when a cold or hot substance touches the skin), but it may also be a distance affect (as when we are warmed by the radiation from the sun). Now there are receptor organs which are stimulated, or affected, by changes that occur within the body itself; thus when we lift anything we have a feeling of effort (the muscular sense); when we walk we have also sensation arising from pressure set up in the joints; when the body is in different postures there is sense of equilibrium, which is something quite apart from seeing or hearing (for it can arise when a man is blindfolded and has his ears plugged); and there is also general sensation from the viscera, for a man may experience stomach-ache. In these cases receptor organs in the muscles, tendons, joints, ears, and viscera are stimulated, producing what we call proprio-sensation. Emotion (that which moves us), blushing, the pallor of fear, trembling, rigidity, even the "Rabelaisian effect of fear on the bowels" ("affective tone or feeling," as it has been called), are the results of the stimulation of the proprioceptors.

Here, in spite of the warning given above, we are speaking of sensation as it results in "feeling," or consciousness, because it is very difficult to avoid doing so; but, nevertheless, the activity of the receptor organs, in so far as we are about to relate it to the initiation of movement, need not be accompanied by any affection of the mind.

The Nervous Links.

Certain mechanisms intervene between the receptor organs on the one hand and the motor organs on the other; these are the peripheral and central nervous systems. Proceeding from a receptor organ there is an *afferent* nerve ("afferent" because it conveys something *to* the central nervous system), and proceeding from the motor organ there is an *efferent* nerve ("efferent" because it conveys something *from* the central nervous system). The reader must understand clearly that a motor organ is (in general) not directly stimulated to act by something that occurs outside the body; it is stimulated *via* the central nervous system. Receptors and afferent nerves are therefore "the way into" the brain and spinal cord, while efferent nerves and motor organs

are "the way out." When the animal does anything in response to some change that occurs in its environment—(1) a receptor organ is stimulated by the external event, (2) an impulse is propagated along an afferent nerve into the central nervous system, (3) some change occurs in the latter, (4) an impulse is propagated out along an efferent nerve, and (5) the motor organ is stimulated, and responds by some kind of movement.

The Minute Structure of the Nervous System.—Complicated as this is, its general scheme is easily understood. In a receptor organ there is always an essential part which we call the nerve

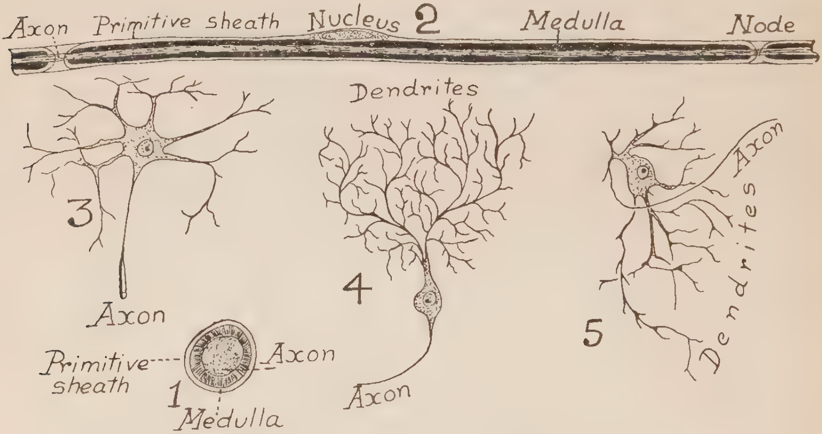

FIG. 8.—FORMS OF NEURONES. ALL HIGHLY MAGNIFIED.

1, Transverse section of a nerve fibre; 2, a nerve fibre; 3, nerve cell from the spinal cord; 4, nerve cell from the cerebellum; 5, nerve cell from a sympathetic ganglion.

termination; this is the retina in the eye, the auditory hairs in the ear, and so on. Between the receptor and the brain or spinal cord there are stretched a series of nerve fibres, and it is along these that the impulse passes. In the central nervous system there are collections of nerve cells and nerve tracts. Between the centre and the motor organ there are other fibres, and in the former there are, again, nerve terminations.

All this structural detail is built up of nervous elements called *neurones*.

Neurones are structures that vary greatly in appearance and size, but they have all the same general form. Each of them consists of a nerve cell—that is, a minute fragment of specialised

protoplasm containing a nucleus. From one side of such a cell there arise one or more prolongations of the protoplasm, and these branch repeatedly to form a plant-like growth—an arborisation—which is known as the dendritic system of the cell. From some other part of the cell there arises a delicate filament which does not usually branch, but is prolonged out into a long thread, the nerve fibre. As Fig. 8 shows, this fibre, which is called the **axon** of the cell, becomes invested in a sheath, and between the sheath and the axon there is a sort of packing, the medulla. The axon may be very long; thus the cells of the grey matter of the spinal cord send out axons into the sciatic nerve, and some of these may be about 3 feet in length, though the nerve cell itself is only about $\frac{1}{500}$ to $\frac{1}{250}$ inch in diameter. The axons, of

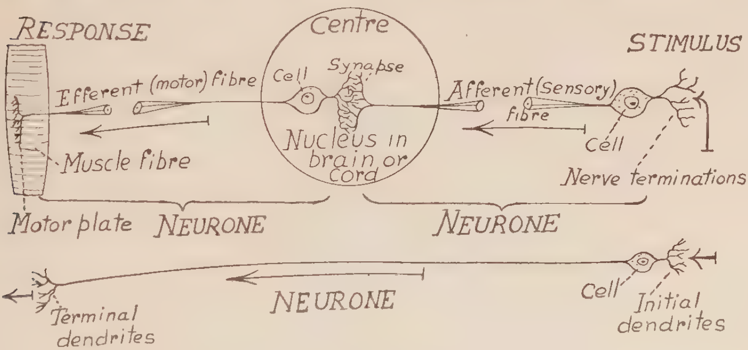

FIG. 9.—DIAGRAM OF THE WAY IN WHICH NEURONES ARE CONNECTED.

course, constitute the nerves. At the extremity away from the nerve cell the axon always breaks up into a second series of dendrites, or terminations.

The essential part of a sense organ such as, for instance, the retina of the eye, or the auditory cells and hairs in the organ of Corti in the internal ear, always consists of the proximal part of a neurone, or even of several neurones, each of which has usually a very short axon. It is always the dendrites of a nerve cell that receive the stimulus, and the latter is always conducted along the axon from the nerve cell to the other terminal arborisation. Thus nerves invariably conduct impulses in one direction only.

Neurones are always connected together by means of **synapses.** At a synapse the distal dendrites of one neurone come into close proximity to the proximal dendrites of another neurone. As

Fig. 9 shows, the two series of dendrites do not touch each other, but the branches of the arborisations "interdigitate." They approach each other very closely, but there is always a space between them, and this space is, of course, filled by other tissue or by liquids. This mode of joining up of successive neurones to form a chain is universal throughout the nervous system, both in the central and the peripheral regions.

An Example of Sensori-Motor Activity.—We shall take what is, perhaps, the simplest and most convenient common action, that of "winking." When something unexpectedly and rapidly approaches the face, the eyes "instinctively" close in order that they may be protected. Now this action of closing and subsequent reopening involves a receptor organ, an afferent

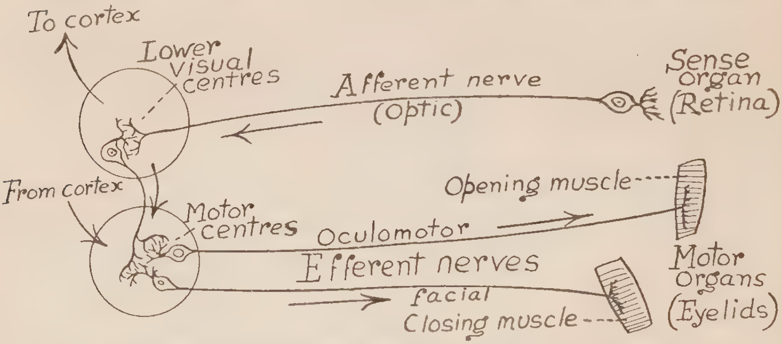

FIG. 10.—SCHEME OF THE NEURONES CONNECTING THE RETINA WITH THE MUSCLES OF THE EYELIDS.

nerve, a nerve centre, an efferent nerve, and a motor organ. The receptor is the retina of the eye. Light reflected from the moving object forms a minute picture on the retina, and in some way the proximal dendrites (which in this case, however, are not dendrites in the usual sense, but rather the rods and cones of the retina) are affected by the variations in light and shade (that is, by differences in the intensity and quality of the radiation), and nervous impulses are set up which travel along the axons of the retinal nerve cells in the optic nerve to the brain. There they are received by a nerve centre. and the afferent impulse is converted into an efferent one, which travels out from the centre, *via* the axons of the nerve cells there, through two nerves. One of these is the third cranial, or oculo-motor nerve, and the other is a branch of the seventh cranial, or facial nerve. The former

goes to the lifting muscles of the eyelids, and the latter goes to the closing muscles. The same event in the centre gives rise to both impulses simultaneously, and that travelling along the oculo-motor nerve causes the opening muscles to relax, while that which travels along the branch of the facial causes the closing muscles to contract. The eyelids thus close. Immediately afterwards the series of events is reversed because of a second pair of efferent impulses; the opening muscles now contract, and the closing ones relax, and so the eyelids open.

Representing this series of action in a very schematic way, we get the diagrams given on pp. 28 and 29.

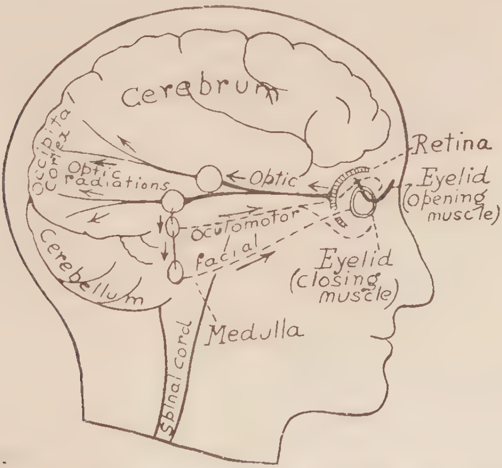

Fig. 11.—Scheme of the Connections between the Retina, Brain, and Eyelids used in the Act of Winking.

According to the figure, there is only one proximal set of dendrites in the retina; in reality, there are three (as is represented in Fig. 30, p. 107). Further, only one centre is shown, but really the optic nerve ends in three centres in the mid-brain (see Fig. 32, p. 115). From these centres other neurones make connection with the oculo-motor centre, and from the latter another set of neurones pass out along the oculo-motor nerves to the opening muscles, while yet another traverses the nucleus (or centre) of the facial nerve, and go out through the latter to the closing muscles of the eyelids.

In any activity of the sensori-motor system, then, a rather complicated mechanism is involved. Some change occurring in

the environment acts upon a receptor organ by stimulating the proximal dendrite of a nerve cell, and thus setting up a nervous impulse which travels up the axon of this cell into a nerve centre, or nucleus, or ganglion, in the brain or spinal cord. The axon ends in the centre as a series of distal dendrites, which form a synapse with the proximal dendrites of another neurone. The axon of the latter leaves the brain or spinal cord in an efferent nerve, which goes to the muscles concerned. The impulse travelling out is distributed to the muscle fibres by the distal dendrites of the final neurone, and, entering the muscle, it *releases energy* and causes the latter to contract or relax, thus causing the movement.

This, it must be remembered, is only a scheme of the mechanism, and we elaborate it in Chapters VI. to VIII. Meanwhile, it will suffice to give the reader a preliminary notion of what are the essential activities of the sensori-motor system.

CHAPTER III

THE PRINCIPLES OF ENERGY

So far our description of the animal body has been that of a mechanism which can be actuated, or made to "go." How it is actuated—that is, what are the sources of its energy, and how these sources are utilised—is the subject of the following chapter. Meanwhile, however, something must be said about the general principles of energy in so far as they concern us in our study of life. First, then, we ought to consider what is meant by

The Nature of a Material Body.

A material thing or body is something that is heavy; that has shape, or occupies space; that coheres and is dense in varying degrees; that has heat, also in varying degrees; that has texture, lustre, colour, smell, and taste. In short, a material body is a massive substance which has physical "properties."

Coherence.—Material bodies may be solid, liquid, or gaseous. When they are solid they can be disintegrated by mechanical means—that is, they can be crushed, broken, powdered, filed, etc.—and therefore they must consist of smaller parts that cohere together, but which can, nevertheless, be separated. There appears to be a limit (in the practical sense) to the degree to which a solid material can be pulverised, though we can reduce it to exceedingly fine particles. By-and-by, however, our mechanical means of disintegration fail to make the particles any finer, but in imagination we can still divide them.

The chemist can show that the finest particles to which a body can be reduced are still aggregates of **molecules**, and thus he regards the latter as the very finest particles to which a material body can be reduced without losing its specific properties. Molecules are therefore the ultimate particles of which bodies are made up, and they cohere together more or less strongly, or not at all. When the degree of cohesion is such that the body preserves its shape irrespective of anything that contains it, we say that it is solid; but when the molecules still cohere, but slip on each other, we call the body viscous (as in the cases of pitch or

syrup), or liquid (as in the case of water). When they do not cohere at all, so that the material can take any shape and expand to any extent, we call it a gas. Thus in ice the molecules cohere strongly, but not nearly so much when the ice is melted, and hardly at all when the water is converted into steam.

Temperature and Heat.—Now all bodies of which we have any experience possess some heat. Heat is a "mode of molecular motion"—a form of energy—and the intensity of heat (but not its quantity) depends on the rapidity of motion of the molecules. At a temperature of 273° C. below the freezing-point of water all movements of the molecules themselves (but not of the parts of the molecules) cease, and this temperature is the absolute zero, and is approximately that of cosmic space. When the temperature rises, the molecules move more rapidly until they become loosened from, but still attract, each other; then the body melts. Rising in temperature still more, the molecules finally cease to attract each other, and each of them moves freely so that they tend to fly apart; then the body becomes a gas. The temperatures at which melting and vaporisation occur are, of course, different ones in different materials, and depend on the nature of the molecules of which the body is composed.

When bodies are at different temperatures, heat tends to flow of itself from the warmer to the colder body. If, when we touch a body, heat flows from it to our skin, we say that the body is warm, and if the converse happens, we say that the body is cold.

Density.—The more molecules there are in the same bulk the denser, we say, the body is. Thus a square inch of ice contains a certain number of molecules of H_2O, and the substance has a certain density; but when the ice is melted and the temperature of the water rises to, say, 65° F., the same number of molecules now occupies a greater volume (for they are further apart), and so the density becomes less.

When the water is raised to, say, 220° F., it is converted into steam, and it now occupies over 1,700 times the volume it had in the liquid state. Therefore its density is very much less. This means that the density of a body depends on the closeness with which the molecules are packed, or cohere together. But it also depends on the relative weights of the molecules, for some are heavier than others; thus the molecules of quicksilver are, each of them, much heavier than those of water.

Texture and Lustre.—This depends on the ways in which the particles are, so to speak, laid alongside each other; thus polished steel has a smooth texture, but that of a fractured piece of steel is rough and crystalline. Lustre is a kind of texture, the body exhibiting it being very smooth, so that it reflects the light that falls on it.

Colour.—This depends on the chemical nature of the molecules, and on the ways in which they are arranged together. Gold, for instance, when highly polished, has bright, metallic lustre, and is yellow in colour, but when it is finely divided it may be purple. Sunlight is a mixture of light of different colours, or wave-lengths, and material bodies can act differently on this mixture. When the proportions of the lights of different wave-lengths reflected from a body are the same as the proportions in sunlight, the body appears white (or grey) to our eyes. When all the light that falls on a body is absorbed by it, none being reflected, we say that the latter is black. When some of the wave-lengths are reflected and others are absorbed, we say that the body is coloured. Thus rouge absorbs all the light falling on it except that which has the wave-length associated with what we call scarlet; it reflects this kind of light, and so it appears coloured. In monochromatic light—that is, light of one colour—all bodies look as if they had the same hue, only brighter or duller.

Smell and Taste.—Most bodies give off fine particles into the air, and these become inhaled into our nostrils. If such particles can dissolve in the liquid bathing the olfactory mucous membrane, they can react upon or stimulate the nerve terminations in the latter, and so they give rise to the sensation of smell. If a substance placed on the tongue can dissolve and affect the termination of the gustatory nerves, we have the sensation of taste.

Different Kinds of Molecules.—The molecules, or ultimate particles of which material bodies are composed, are not all the same; for instance, quicksilver consists of molecules of the chemical substance mercury, and water consists of molecules, each of which consists of three atoms (H_2O), two of hydrogen and one of oxygen. Molecules are therefore made up of atoms, and there are about 100 different kinds of the latter. All material bodies, of whatever nature they may be, are therefore composed

of molecules, each of which contains a relatively small number of one or more kinds of chemical atoms.

Now colour, smell, taste, lustre, texture, temperature, and density, are dependent on the chemical nature of the molecules, and on the ways in which the latter are arranged and on their motions. Thus water may be warm or cold to our sense, but it consists in each case of the same molecules moving relatively slowly when the water is cold, and relatively quickly when it is warm. Phosphorus may be yellow or red, and in the former case it is odoriferous, poisonous, and combustible; while in the latter case it has no smell, is not poisonous, and is non-inflammable in the conditions in which yellow phosphorus is inflammable. Yet the substance phosphorus is chemically the same in both cases, only the atoms are in different configurations. The same number of molecules of H_2O may be dense in the form of ice, less dense in the form of water, and less dense still in the form of steam, according to the distances that its molecules are apart from each other. Something, however, is the same in the case of the red and yellow phosphorus, or the solid, liquid, and gaseous water—that is, the mass of the chemical substance itself. Apparently colour, taste, smell, density, temperature, etc., may be variable, while mass remains invariable.

Weight and Mass.—Weight itself is something that may vary, while mass remains the same. A material body weighs more at the earth's poles than it does at the equator, and if it could be transported to the sun it would be much heavier, or if to the moon much lighter, than it is on the earth. If it could be removed to several millions of miles away from any cosmic body its weight would be almost nothing. Weight depends on the mass of the body, on its distance from some attracting body (such as the sun, earth, or moon), and on the mass of the latter. The mass of our material body would be the same everywhere (we are neglecting some physical results included in the theory of relativity), but its weight would vary.

Mass.—Something, then, seems to be invariable, or nearly so, and this is the mass or quantity of matter in a body. The mass of a cubic inch of iron is so much in all circumstances, and that of a cubic inch of gold is more than that of the same bulk of iron, but is also invariable. By the quantity of matter, or mass of a body, we therefore mean the number of molecules in the body multi-

plied by their molecular weight. (The molecular weight of the lightest molecule, that of hydrogen, H_2, is taken as the standard to which all other molecular weights are applied.)

Mass and Inertia.—Mass is, then, the most fundamental thing in our notion of materiality, but it is not an irreducible conception, and we must seek for some way of defining and measuring it. Note, first of all, that we have a bodily intuition of mass: let there be two exactly similar stoneware, corked bottles, and let one be filled with water and the other with mercury. We cannot say which is which merely by looking at them, but we can distinguish if we lift them, for a greater degree of effort of our muscles is necessary to lift the mercury than to lift the water, and we have the "feeling" of this effort.

Nevertheless, such an intuition would be mostly useless to us, for it would not apply to great masses which we cannot lift, nor to very small ones, nor to masses which were nearly the same. We must have some way of measuring mass by taking some dimension of space, or by counting (or numbering) something. Now there is a constant and universal property of masses—that of gravitation; all material bodies, whatever their nature, or mass, fall to the surface of the earth when they are free to move. If they are sufficiently far away they will fall 16 feet in the first second, 64 feet in the first two seconds, 144 feet in the first three seconds, and so on, their rate of fall being accelerated by 32 feet per second per second during the time that they are falling. We do not know in the least what the force of gravitation is, but we know precisely what it does—it accelerates the rate of motion of a body free to fall. Consider what this means: there are three factors—mass, space, and time; a mass, when it is attracted by the earth, falls with increasing velocity—that is, it falls through a greater space in the third second than in the second one, and through a greater space in the second one than in the first. This acceleration of the motion of a mass during a certain time we shall call the work done by the force (whatever the latter may be).

Place a mass of metal (say a pound weight) in a scale pan; it will fall, and the other scale pan will rise. Now place another pound weight in the other scale pan, and the two will balance each other so that neither falls. The work done by gravity on the one is equal to the work done on the other: neither is accelerated; the space and time factors are the same, and therefore the masses are

the same. Take a piece of wire of uniform diameter and density, and (say) 10 inches long, and put it in one scale, and put a piece of the same wire 1 inch long in the other. The mass of the 10-inch length will be greater than that of the 1-inch piece, for the scale pan in which it is placed will fall, and the other one will rise. Put a 1-inch length in one pan and another 1-inch length in the other, and it will be found that the work done by the earth's gravity is the same in each case, and the masses are therefore equal. Finally, put the ten 1-inch pieces in one pan and the 10-inch piece in the other, and again it will be found that the work done is the same in each case, so that the mass of each 1-inch length is one-tenth of that of the 10-inch length.

Thus we can find the mass of a body by measuring the work done upon it, when it is free to fall, by the earth's gravity, and comparing this with some standard amount of work done. In whatever way we measure this work done it will be found that we always measure a space. Even when we measure time it is really a space that we determine.

A material body that is in a state of rest will continue in a state of rest, or if it is in a state of uniform motion it will continue in that state of motion unless work is done upon it. Of itself it is inert. Its inertia varies according to its mass, so if a greater mass that is at rest is to be moved, or if a greater mass that is in uniform motion is to be stopped, a greater amount of work must be done. Inertia means the tendency of something to remain as it is, unless some external agency acts upon it.

Modern Theories of Matter.

We must say a few words about these. Not so long ago it was thought that all material bodies, or kinds of matter, were built up of chemical atoms which were the ultimate particles. An atom was regarded as indivisible. But some atoms were known to be heavier than others, and so their masses were not the same; thus the mass of an atom of platinum is about 194 times greater than that of an atom of hydrogen. Therefore, the heavier atoms had more of something in them than the lighter ones, but more of what? There might be some universal kind of matter contained in greater quantity in the heavier than in the lighter atoms, but if so the former could hardly be thought about as indivisible, which they must be, according to chemical theory.

The way out from this paradox was found by the discovery of

radio-activity. As the result of the physical research based on this, it became very probable that an atom (which is still the smallest particle of matter as such that can exist) is really complex, and consists of a system of **electrons.** An electron is not material, but is an unit charge of electricity, the smallest charge that can exist. In the centre of the atom there is an electron, and revolving round this there are others, much in the way the planets are revolving round the sun in the solar system. Now one or more of the electrons can be expelled from the system, and then the latter becomes a new kind of chemical atom. Different atoms contain different numbers of revolving electrons.

What is an electron ? All we can say about it is that it is electricity, and not material. Thus, materiality dissolves into energy, and the latter is the fundamental physical reality. Mass disappears, but inertia remains, only the latter is now electro-magnetic inertia.

The Capacity for Doing Work.

Things, then, remain as they are unless something is done to them. A train remains at rest unless work is done upon it, causing it, for instance, to attain a velocity of thirty miles per hour three minutes after it has started to move. Conversely, the train will continue to run after the steam has been shut off unless work is done upon it, causing it to stop, and such work may be done by the application of the brakes, or by the friction of the air, or that of the wheels on their bearings or upon the rails. The mechanical work that is done in both these cases is measured in horse-power, 1 h.p. being the amount of work done by raising a weight of 33,000 pounds 1 foot high in one minute.

The water in a steam boiler will remain at one temperature unless work is done upon it. Heat must be supplied to the water by the combustion of coal in the furnace. Now we can express the amount of heat in units, which are called **Calories,** each Calorie generated in a second being 5·62 h.p. Thus to raise the temperature of the water in the boiler—that is, to change its state in a certain way—so much work must be done.

An electric tram will stand still upon the rails for ever unless work is done upon it. When the switch is closed electric current enters the motors, and the latter revolve propelling the car and giving it a speed of, say, ten miles per hour in one half-minute. We measure this work done by the current in units, called kilowatts, each of the latter being 1·341 h.p.

A dynamo will remain at rest and yield no current unless work is done upon it, and this also we measure in h.p. Supply motive power equal to so many h.p. to the dynamo, and the latter, with its conductors, changes its state and develops so many kilowatts of current.

Finally, a man may climb a mountain, say 5,000 feet high, in six hours, but not unless certain substances in his body become oxidised, yielding muscular power capable of raising his body against the resistance of the earth's gravity. But, again, he cannot supply this muscular power and do work unless he takes food, and a certain quantity of the latter—that is, so much proteid, fat, and carbohydrate—estimated in equivalent heat units, called Calories, must be supplied before his body can do the specified work.

In all these cases something called the capacity for doing work is added to the thing that changes or does work. Chemical substances (the fuel and oxygen) are burned in the steam boiler, electric current is fed into the motor, mechanical motion is imparted to the dynamo, and chemical substances are assimilated into the muscles of the mountaineer. All these things represent the capacity for doing work, and the latter we define more shortly as **available energy.**

Obviously there are different forms of available energy, and these can be transformed one into the other. There is mechanical energy, that of the motions of material bodies—for instance, the motion of the parts of the locomotive engine; heat energy—that is, the enormously increased velocity of movement of the molecules of something or other; electric energy, which is the flow of electrons through a conductor; muscular energy (about which we know very little); gravitational energy; the energy of radiation, etc. We know little or nothing of what these various forms of available energy are, although we recognise them as different, for they affect our sense organs differently; thus we recognise mechanical energy because we exert muscular power in opposing it; we recognise heat through the stimuli of certain sense organs; radiation usually by the stimuli of the retina (and also of the skin); electric energy mainly by its stimulation of the muscles, and so on.

But all forms of available energy can be converted one into the other, and all of them are the capacity for doing work, or more generally the state of something or other. But, again, in what-

ever form this capacity for doing work may exist, it can always be measured, directly or indirectly, as a certain quantity of mechanical work performed. That means that we do not know what available energy is, we only know what it does.

Energy Transformations.

We may profitably expand the result stated in the last paragraph, and give some further examples. There is a heap of coal, and this we shall call available chemical energy. It contains certain substances—carbon and hydrocarbons—and these can combine chemically with the oxygen of the air to form carbonic acid gas and water (with some other substances). In this act of chemical combination heat is generated. If the burning fuel is confined in a furnace, a large fraction of the heat may be communicated to the water contained in a steam boiler, and its effect is to increase the motions of the molecules of the water. By-and-by these motions become so rapid that the molecules fly apart and the water is converted into steam. Later on the velocities of the molecules of the steam are increased by the further flow of heat from the furnace, and they collide with, and rebound from, the walls of the boiler in which they are contained, thus setting up steam pressure.

> The chemical energy of the fuel is therefore transformed into the kinetic energy of the molecules of steam under pressure.

The steam is then allowed to expand into the cylinders of the engine, and in so doing it pushes out the pistons and communicates a rotatory motion to the crank shafts.

> Thus the kinetic energy of the molecules of steam is transformed into the kinetic energy of the large, moving parts of the engine—that is, into mechanical energy.

The motion of the engine is next communicated, by means of shafting or belts, to the armature of a dynamo. When the latter revolves it generates an electric current, and this uses up the mechanical energy; for if the switch of the dynamo is open, relatively little power is required to rotate the latter, and no current passes. But when the switch is closed, relatively much power is required, and a current is generated.

> Mechanical energy therefore transforms into electric energy.

The current generated can now be used in various ways; for instance, it can be sent through lamps, when the latter glow; or it can be made to decompose clay, producing aluminium; or it can be fed into motors, generating mechanical energy; or passed through electric fires, generating heat.

> Thus electric energy transforms into radiant (light) energy; into available chemical energy; into mechanical energy; and into heat energy.

And so on; summarising the example we have given, and many others that might be quoted, we get our first principle of energetics:

> *Any form of available energy can be converted into any other form* .. .. (1)

The Diminution of Available Energy.

We come now to a very important result. Returning to the series of examples just given, we note that a certain quantity of coal contains chemical energy, and that the latter may be converted into heat. The quantity of heat which can be generated by the combustion of the coal can be estimated in the following manner: A small weighed piece is powdered, mixed with some substance which yields free oxygen, and is placed in a kind of bomb, which is put into a vessel containing a known mass of water at a known temperature. The mixture of coal and oxygen-yielding substance is fired electrically, and precautious are taken that all the heat generated goes to raise the temperature of the water. The result is that a certain quantity of water, say 1 kilogram (=2·2 pounds), is raised in temperature, say 1° C. That quantity of heat is called a Calorie, and so we estimate the "calorific value" of the coal—that is, the quantity of heat that is generated when an unit mass is burned.

Now let the coal be burned in a steam-boiler furnace, and let the steam produced work an engine. The work developed by the latter can easily be estimated, and so we can find the number of h.p. given per ton of coal, or per Calorie. Next, use the engine to drive a dynamo, and use the current generated by the latter to drive an electric motor. Suppose that we utilise the entire power of the engine to drive the dynamo, and the entire current given by the latter to drive the motor. Now estimate the h.p. developed by the motor, and compare it with the h.p. developed by the engine; it is much less.

Or use the entire power of the current to work a series of electric fires, and estimate the quantity of heat generated by the latter; it is very much less than the quantity of heat originally generated by the burning of the coal that raised the steam, that worked the engine, that drove the dynamo, that produced the current, that generated the heat of the electric fire; or, again, estimate the h.p. required to drive the dynamo, use the current given by the latter to drive a motor, and then estimate the h.p. developed by the latter; it is about 5 to 10 per cent. less than that required to drive the dynamo.

Finally, estimate the number of kilowatts of current required to work a motor, and then employ the latter to drive a dynamo, and measure the current generated by the latter; it is less (5 to 10 per cent.) than the current originally used to drive the motor.

That means that there is waste incurred whenever there is an energy transformation, and it is quite easy to see how this waste occurs. When coal is burned in the furnace of a steam boiler, a quantity of heat is lost by radiation from the boiler and furnace doors, and another fraction is carried away through the flues into the atmosphere; there is radiation from the steam pipes and hot cylinders, and still another fraction of heat is given up to warm the condenser water. Thus all the heat generated by the combustion of the coal does not transform into the mechanical energy of the engine; in fact, only about 10 to 20 per cent. does so. Further, there is friction in the bearings, slides, etc., of the engine, and so mechanical energy is lost. In communicating the engine power to the dynamo more friction is incurred. In the dynamo itself there is friction, and some of the current developed is wasted on heating the parts of the mechanism, while more is lost by imperfect insulation. These latter sources of loss also exist in the means whereby the current is transmitted and then converted into radiant energy, or heat, or mechanical energy. When the current is used to generate light there is great loss, for heat must first be generated until the intensely hot filaments, or arc, or vapour, glow. If light could be generated directly from chemical action—as it is by a glow-worm—there would be great economy.

Thus there are a host of ways in which available energy is lost in the course of its transformations. There is friction, imperfect heat conduction and insulation, imperfect electric conduction and insulation, materials which are not perfectly elastic or perfectly rigid, etc. In all cases this lost energy reappears as low-

temperature heat, but the latter is unavailable energy, and we cannot transform it.

Thus we get our second principle:

> *In all transformations of energy some of the latter becomes unavailable. Thus the capacity for doing work continually diminishes* .. .. (2)

Now consider another notion which is really involved in our second principle, but which it is useful to discuss separately; that is, the notion of—

Reversible and Irreversible Transformations.—Take a suitable form of dynamo and cause it to revolve, thus generating a current of, say, K kilowatts, by the expenditure of, say, H horse-power. Then take K kilowatts of current, and supply it to the dynamo, when the latter will begin to revolve and will act as a motor. Thus the same machine is reversible; when current is supplied it will generate mechanical energy, and when mechanical energy is supplied it will generate electricity.

But notice particularly that we supplied K kilowatts of current, and got H horse-power. Now if we supply H horse-power, we only get about 95 per cent. K of current. Therefore our reversibility is not quite perfect; if it were we should have got K kilowatts of current, instead of 95 per cent. K.

Take the case of a steam engine and consider its theory. We have a " working substance," the water in the boiler. Now let this working substance be heated; it expands enormously, does work by moving the pistons, and finally escapes into the condenser, where it heats up the circulating water. Therefore, the working substance takes heat from the steam boiler, converts some of this heat into mechanical work, and gives up some to the condenser. Now let the water in the boiler cool down, and try to reverse the process by actuating the engine in the opposite direction. If the mechanism were reversible, heat would be taken from the condenser, the mechanical work done on the engine from outside would transform into heat, and these two quantities of heat would be transferred to the water in the boiler, heating up the latter to boiling-point and beyond, and so establishing steam pressure. This cannot be done (in practice), and so the steam engine is an irreversible mechanism.

Take a very famous experiment and try to reverse it:

Joule, in 1843, caused a paddle-wheel to revolve in water con-

tained in a heat-insulated vessel. He took all possible precautions, measured the amount of mechanical work done (by causing a falling weight of known mass to actuate the paddle), and measured the mass of water and the rise of temperature produced by the friction of the paddle. He found what is now called the "mechanical equivalent of heat"—that is, he found that when a weight of 1 kilogram falls through 427 kilometres, 1 kilogram of water is raised in temperature 1° C. This amount of heat communicated to the water is called 1 (large) Calorie. Now imagine the water contained in the mechanism to be heated up 1° C.; if the latter were reversible the paddle would revolve. But it does not, and the apparatus is therefore irreversible.

Finally, make the end of a poker red-hot in the fire, and then take it out and let it stand; it will cool down, and in half an hour or so it will have attained the temperature of the air in the room. Its heat has been lost by radiation and convection, and has gone to raise the temperature of the air, furniture, and walls of the room ever so little. Imagine the experiment to be reversed, so that the heat of the room would flow into the end of the poker and raise its temperature to redness; such an effect has never been observed to occur (though if it did occur physicists would not be incredulous!). Therefore the flow of heat, *of itself*, is irreversible.

These examples will enable us to formulate two more statements:

> *Some energy transformations are approximately reversible and others are irreversible* .. .. (3)
>
> *The flow of heat (of itself) is irreversible, only going from a hot to a cold body* .. .. (4)

Thus we can, quite easily, cause some energy transformations to occur, but not so easily, or not at all, some others.

We can easily cause all kinds of energy to transform into heat, and, in fact, they do transform into heat of themselves. Mechanical friction always generates heat, chemical action generally produces heat and sometimes chemical energy completely transforms into heat; the flow of electricity through a conductor, the straining and bending of materials (internal friction), the reception of light by substances—in short, all physical reactions—transform, or tend to transform, into heat. Therefore—

> *All forms of available energy tend to be transformed into heat, but heat is not at all, or it is only with difficulty and loss, transformable into other forms of available energy* .. (5)

And that is why there is always waste, or loss of available energy, and it is why the capacity for doing work tends to diminish indefinitely in the universe as we know it.

Quantitative Energy Transformations.—The following statements are the actual results of experience:

(*a*) 1 *horse-power*=33,000 *foot-pounds per minute.*

That is to say, the amount of mechanical work that would be done against the earth's gravity when a mass of 33,000 pounds is raised 1 foot in one minute, or conversely the amount of work done by the earth's gravity when a mass of 33,000 pounds falls 1 foot in one minute, is called a horse-power. Long ago British engineers found, by actual experiments, the strength of an average cart-horse as measured in the above ways, and the quantity so found was, later on, adopted as a mechanical unit.

(*b*) 1 *h.p.*=0·178 *Calorie per second.*

This means that when the work done by a mass of 33,000 pounds in falling 1 foot in one minute is completely changed into heat (which it can be experimentally), 10·8 kilogram of water is raised 1° C. in temperature.

$$\left.\begin{array}{ll}(c)\ 1\ \textit{gram of fat} & =9{\cdot}3\\ \ 1\ \textit{gram of proteid} & =4{\cdot}1\\ \ 1\ \textit{gram of carbohydrate} & =4{\cdot}1\end{array}\right\}\text{Calories, when burnt in the body.}$$

These are statements of the convertibility of chemical substances into heat. They mean that when certain quantities of combustible materials are burned in oxygen, certain quantities of heat are generated. Many more instances might be given. The transformations are complete ones—that is, all the available chemical energy transforms into heat energy.

(*d*) 1 *kilowatt*=0·239 *Calorie per second.*

That is to say, when a current is sent through a conductor against a resistance it transforms into heat. Some of the current (=1 kilowatt) disappears, and a certain quantity of heat (=0·239 Calorie) is developed. The heat developed is energetically equivalent to the current that disappears.

Now, since 1 kilowatt=0·239 Calorie per second, and 1 h.p.=0·178 Calorie per second, it follows that—

(*e*) 1 *kilowatt*=1·341 *h.p.*

And by reversing statements (*b*) and (*d*) and (*e*) we get—

(*f*) 1 *Calorie per second*=5·62 *h.p.*
(*g*) 1 *Calorie per second*=4·18 *kilowatt*
(*h*) 1 *h.p.*=0·746 *kilowatt.*

But equations (*e*), (*f*), (*g*), and (*h*) are only true in theory, and they are not true in practice. They would be if equations (*b*) and (*d*) were reversible, which they are not. And that shows that we must make a very clear distinction between available energy (which is the capacity for doing work) and energy in the abstract, which is understood when we disregard experience and consider all transformations as reversible ones.

Energy in the Abstract.

When an energy transformation occurs, one kind of available energy is converted into other kinds; for instance, so many cubic feet of coal gas are supplied to a gas engine, which then does mechanical work. Now the "calorific value" of the gas can easily be determined—that is, we can find the quantity of heat into which the chemical energy of the gas is completely transformed when it is burned. So, also, the heat equivalent of the work done by the engine could be determined; for instance, the latter could be employed to lift a mass against the earth's gravity, and then this work can be represented as heat by using the mechanical equivalent in heat of this work done [equation (*b*), p. 44]. There will be a balance, for the heat equivalent of the gas is greater than the heat equivalent of the work done by the engine, and so available energy is lost. But we know very well that this available energy is really lost as heat radiated away from the engine, lost in the products of combustion (which are still hot when they are blown out into the air), and by other "leakages." And so the energy is not really destroyed, but simply dissipated. In many cases it can be traced, and where it cannot be traced we assume that it might be. This leads us to consider energy in the abstract without considering whether or not it is available, or possesses the capacity for doing work.

First of all, however, we must make the concept of *an isolated system.* Let there be a large island which has absolutely no commerce or other communications with the rest of the world. It produces all that its inhabitants require, and it utilises itself all that it produces. It is self-sufficient, and is economically an

isolated system. So we might imagine an apparatus, or experimental plant, containing its own source of energy and absorbing itself all the energy given off, or wasted, or dissipated. That would be an isolated, energetic system. It is true that such an isolated physical system is a fiction, for there must always be some interchange of energy between any apparatus that we can devise and work and its surroundings; the only really isolated physical system is the entire universe. But let it be possible to take account of the energy lost by the system to without, or received by it from without; then we approximate to our concept of physical isolation.

Making all allowances, then, for experimental error, friction, loss of heat by radiation, convection, and conduction, imperfect rigidity and elasticity of materials, etc., we can, very approximately at least, trace the quantity of available energy that becomes unavailable, or is dissipated. Thus we arrive at our fundamental principle of energy:

In all the transformations undergone by an isolated system the total quantity of energy contained is neither increased nor diminished .. .. (6)

This is the law of conservation of energy, and it means that although the capacity for doing work—that is, available energy—diminishes, energy in the abstract does not diminish. When available energy diminishes, unavailable energy always appears in its place. Very often we can prove this. If we cannot do so we assume the law, and our assumption is always justified by other experimental results. But we are compelled, anyhow, to make the assumption, because the law of conservation is an *a priori* mode of our thought. To this matter we return later.

We may now state the principal result of our work in the form of a quotation: "In all the transformations of a material system considered in this book, there is a certain entity which (1) remains constant in quantity, and (2) is capable, under certain conditions, of assuming the forms of kinetic and potential energy, which are dealt with under the study of Rational Dynamics. This Entity is Energy."*

Several points arising from this definition must now be discussed: first of all the nature of "Rational Dynamics." In this

* G. H. Bryan, *Thermodynamics*, Teubner's *Lehrbuchen der Mathematischen Wissenschaften*, xxi., Leipzig, 1907.

department of science we deal with the behaviour of material bodies that "obey" Newton's laws of motion. There is no friction; bodies are perfectly rigid or perfectly elastic, and everything happens in an ideal world where all events can be described strictly mathematically. We do not consider heat at all, and energy is always mechanical, and is either potential or kinetic. There is no dissipation, and all transformations are reversible ones. In such circumstances "energy" is an entity that can be defined as above.

Potential and Kinetic Energy.

Sometimes available energy seems to vanish, although it is not converted into unavailable energy, or dissipated. Thus a grandfather's clock has stopped because its weights have run down, and we proceed to wind up the latter, but do not start the pendulum. In doing so we have expended muscular work, which is measured by the masses of the weights and the distance through which they have been raised. But the clock doesn't "go" until the pendulum is given an initial swing, and we have thus to account for the energy which we have expended. Now the system, clock and weights, and the earth, is in a different state from what it was before the weights were wound up, for the latter are now some 5 feet further away from the centre of the earth than they were when the clock had run down, and they are therefore free to fall. So long as the clock is not started, the weights possess potential energy—that is, energy of position relative to something else. When the clock is started the weights begin to descend, and the potential energy begins to transform into kinetic energy, which is the energy of a mass in motion. Call M the mass of the weights and V the velocity with which they fall, and we get $\frac{1}{2}MV^2$=the kinetic energy developed. During the time of fall the potential energy decreases, and the kinetic energy passes into the unavailable form, for the friction of the wheels, etc., generates heat, which is radiated away. When the weights have reached the bottom of the case they are no longer free to fall, and the system contains no more potential energy that is available for doing work—at least, so far as the clock itself is concerned.

Think about a mixture of oxygen and hydrogen in the proportions of one molecule of the former and two of the latter; this system contains potential chemical energy. It will remain a

mixture of oxygen and hydrogen for an indefinite period of time, nothing happening in it. But let a spark pass through the gases, and they will combine together with an explosion and generation of heat, and the potential energy which they contained transforms into the kinetic form. Prior to the explosion the mixture might be represented thus:

$$H_2, H_2, O_2, \text{etc.},$$

the molecules of the gases (each of them consisting of two atoms bound together) being apart from, and not influencing each other; but after the spark has fired the mixture we have

$$H_2O, H_2O, \text{etc.},$$

the molecules now occupying a different position relative to each other. Thus chemical energy is energy of position.

Now before the explosion the mixture of hydrogen and oxygen possessed kinetic energy (as a mixture and apart altogether from the chemical nature of its constituents). Each molecule was moving with a certain velocity, and from the temperature and pressure of the gas the average velocity of all the molecules can be determined. The mixture can do mechanical work, for if it were allowed to rush into a vacuum it could drive in a piston just as steam drives in the piston in a cylinder. But as the explosion occurs, the work that the gases can do is enormously increased (thus the explosion can propel a projectile if it is fired in a suitable vessel), and this energy that appears is the increased kinetic energy of the molecules of steam at a very high temperature—that is, the latter are now moving with much greater velocities than were the molecules of hydrogen and oxygen, and so they exert a greater pressure.

The energy therefore becomes manifest, or visible, in its mechanical effects; but where was it before the explosion occurred? We cannot answer this question, and we assume that it was not *in* the molecules of hydrogen and oxygen, but was in the medium between them—that is, in the ether of space. The hypothesis is one that does not lead us astray, and therefore we assume its validity or "truth."

Available chemical energy, the energy of a weight raised above the surface of the earth, and free to fall when it is released, and that of a coiled spring—these are examples of potential energy which transforms into kinetic energy, or the motion of bodies, when a releasing transformation occurs.

Releasing Transformations.

A word about this matter. The grandfather's clock, with its weights wound up, is at rest, but a very small expenditure of muscular effort will cause the pendulum to make a swing, and then the mechanism starts. The mixture of hydrogen and oxygen is also at rest, and nothing happens until a very small spark (involving a very small expenditure of heat) causes several molecules of H_2 and O_2 to combine, thus liberating heat, which starts off other molecules, and so on, until the whole mixture fires in a very small period of time. A stone poised on the summit of a hill remains there until a very small push liberates it, and it starts to roll down, acquiring a high velocity, and becoming capable of doing much mechanical work. The coiled spring of a gramophone remains coiled until the touch of a little lever allows it to uncoil and actuate the mechanism. These are examples of releasing transformations. A relatively large quantity of energy is potential, and because of some condition of "false equilibrium," due to friction of some kind, it remains potential; but a relatively small expenditure of kinetic energy suitably applied upsets the equilibrium or overcomes the friction, and releases the energy which was potential. Such releasing transformations are of much importance in the discussion of organic activity.

The Principle of Becoming.

Taking a general survey of the results discussed so far, we may ask the question, Why does anything at all happen? The enquiry is not so foolish a one as it may appear to a "practically-minded" person, for a little consideration will convince such that if anything happens—if there is "becoming"—there must be an energy transformation. This is true, whether the event that happens is something very great and important from our point of view—for instances, the formation of a huge sun-spot with accompanying magnetic storms, a cyclonic disturbance which wrecks a number of vessels, or a stellar collision—and it would also be true of quite trivial things, such as the condensation of a man's breath on the surface of a shaving mirror. Therefore our question becomes this, Why does an energy transformation occur? And as such it is a legitimate subject for enquiry.

Now in every transformation three things are involved:

1. The **intensity** of the energy (intensity factor).
2. The **quantity** of the energy (capacity factor).
3. The **direction** of the transformation (the sign).

These factors may be illustrated as follows:

The System in which the Transformation occurs.	*Intensity Factor.*	*Capacity Factor.*
A steam engine	Pressure of steam	Quantity of steam
A water motor	Head of water	Quantity of water
An electric motor or lamp	Electric potential (volts)	Quantity of current (amperes)
A source of heat	Temperature	Quantity of heat

In all these cases there is a system in which an energy transformation may occur; thus there may be a steam engine and boiler actuating some mechanism, a water reservoir and wheel, etc. Will a transformation occur in the system, and, if so, what will it do? To be able to predict these occurrences we must be able to specify the conditions under which the system exists. The steam engine will "go" if the pressure of steam in the boiler is considerably greater than that of the atmosphere, and it will continue to go if this pressure is maintained—that is, if new steam is generated as quickly as steam is drawn from the boiler. So, also, with the water mill: the motor will revolve if there is a sufficient head of water, and to keep it revolving the head must be maintained, or the quantity of water in the reservoir must be very great, or must be renewed as fast as it is depleted. If an electric current flows, there must be some way of raising electric potential, for a difference of this is the reason why the current flows. But the quantity of current is also a factor; thus the voltage of an electric stove might be the same as that of a lamp, but a greater quantity of current would be necessary in the former case (for heavier wires are employed). Finally, the temperature of a steam radiator 1 foot square might be the same as that of a radiator 6 feet square, but the quantity of heat distributed by the latter would be much greater.

So there must be a difference of intensity if there is to be a transformation. If a hot-water radiator were at the same temperature as that of the room in which it were placed, there

would be no transference of heat, no matter what quantity of hot water were in circulation. Heat of itself flows from a hotter to a colder region—that is, there must be a difference of intensity in order that the flow may occur.

Why does a chemical reaction occur? Why, for instance, do coal gas and oxygen combine, of themselves, to form carbonic acid gas and water? The reaction is (assuming that the gas is CH_4—that is, marsh gas; it really contains hydrogen and other inflammable substances):

$$CH_4+2O_2=CO_2+2H_2O,$$

and the reaction occurs as if the equation were written from left to right. Why from left to right, and not from right to left? Marsh gas and oxygen combine to form carbonic acid and water, because in doing so a large quantity of heat is evolved; but if CO_2 and H_2O are to combine, a large quantity of heat (or more generally of energy) must be given to them, or be absorbed by them. Therefore they do not combine of themselves, although they can be made to do so. Chemical reactions occur, as a rule, only if heat is evolved, and so we may predict the occurrence if we know that heat may be generated. We cannot enter into the qualifications of this statement, but it may be made more general by saying that a chemical transformation will occur if in the occurrence work will be done. That is "why" it occurs, and if no work can be done by the chemical substances by reacting with each other they will not react of themselves.

And if work is done as the result of the occurrence of a transformation energy will be dissipated, for all work done tends to transform into heat. But, again, all heat generated tends to distribute itself by conduction, radiation, and convection. It cannot of itself accumulate in one place, as it tends to become uniformly diffused throughout the system—the room, the world, and, finally, the whole universe. And so our experience is that in all transformations energy becomes dissipated—that is, intensity differences become levelled down. Therefore we say that an energy transformation occurs of itself if energy can be dissipated, or if intensity differences can be abolished.

This is the *sign* of the transformation. Marsh gas and oxygen react with the evolution of heat and the production of carbonic acid and water. But CO_2 and OH_2 do not react with the production of marsh gas, because heat would be absorbed in this

case; or work is done by the system (CH_4+O_2) in the first case, but work would be done *on* the system (CO_2 and H_2O) in the second case. The latter transformation does not occur unless there is a compensatory energy transformation, a matter to which we return later.

Thus we obtain another principle:

> *Energy transformations will only occur of themselves if energy becomes dissipated—that is, if intensity differences are diminished* .. .. (7)

The principles stated in the course of this chapter are, to some extent, repetitions, and they may be summarised and included in the two fundamental laws of science—the first and second laws of thermo-dynamics. These are:

1. *The Energy of the Universe is Constant.*
2. *The Entropy of the Universe tends to a maximum.**

Now we may, very shortly, examine these statements.

Matter, we have seen, can only be defined in terms of energy, so the first law includes the old statements of the conservation of matter and "force."

But energy was defined on p. 46 as the entity that was constant in all transforming systems, and so there is something in the universe that is constant. This something is energy. Therefore the first law is a definition of energy in the abstract.

Thinking about all this critically, the reader cannot fail to see that the law of conservation is not true without some qualification. It says that there is an entity—an existence—in the universe that can neither increase nor diminish. He will notice that we have experience of nothing but energy transformations, to which, it appears, all existences must reduce. But there are existences which arise from nothing, and are annihilated. These are dreams, hallucinations, "spooks," etc. Our dreams may be vivid and convincing, and "true while they last," and apparitions, if we may fully believe those who have seen them, can have all the appearances presented to us by material things. Obviously disordered sense organs may mislead us, and we may hear noises and smell odours which we may be pretty sure do not come from outside our own bodies. Then there is telepathy, mediumistic control, table-rapping, the planchette, etc., all of

* The concept of entropy is discussed in Chapter XI.

them phenomena about which one hesitates to dogmatise. These things may be, as William James said, "the wild beasts of the philosophical desert," but still they are beasts! We do not get rid of them by saying that they are purely subjective, for we do not seem to be quite clear as to what is subjective and what objective, and whether there is any difference!

But this is quite clear: dreams, apparitions, spooks, telepathy, and the like, are phenomena that are a nuisance, for they are existences that are not conserved, and so we cannot investigate them. They are not energy transformations, for if they were they would continue in some other form after they had disappeared, and then we could count and measure, and describe and weigh them. We cannot do so, of course, and so most scientific men simply do not "believe" in spooks. They are existences, but they are not real existences. *Real things are the things that are conserved.*

And so the law of conservation applies to some things and not to others, and the things to which it does not apply are unreal. That seems to be the best way out of the difficulty.

Nothing that science can possibly do will disprove the law of conservation. Energy seems to vanish, but, if so, we only say that it has become potential. It may appear to come from nothing, and then we say that potential energy becomes kinetic, and we invent an ether of space to give us an abiding-place for potentialities. The discovery of radio-activity is a good example, and we may refer to it. A fragment of diamond can be made to burn, giving off heat, and transforming almost immediately into carbonic acid gas, which can no longer give off heat. A fragment of radium of the same size, however, gives off heat spontaneously, and continues to do so; and a physicist who could observe it for a thousand years would find that it was still giving off heat, but that, like the bush that Moses saw, *nec tamen consumebatur.* To a chemist of the middle of the nineteenth century such a phenomenon would have seemed to be almost miraculous, yet it is doubtful if he would have distrusted the law of conservation. He would, like Sir J. J. Thomson and Sir Ernest Rutherford, have invented a new kind of "bound energy."

He would, like the physicists of our own time, have been justified in his faith. His ether and electrons and bizarre atomic systems are pure inventions, but they are real; they continually lead us back to order and not to chaos, and they are the means

whereby we make discoveries and obtain increased power over material things. They are concepts that can be investigated, inasmuch as they include the notion of conservation.

All this goes to show, does it not, that the law of conservation is an *a priori* one—it is a form of our thought?

Compare it with Kant's "first analogy of experience": "In all changes of phenomena substance is permanent, and the quantum thereof in nature is neither increased nor diminished." Phenomena are, in so far as they are real, energy transformations, and their "substance"—that which underlies them—is energy in the abstract. If Kant's transcendental logic is valid, the first law is a mode of operation of the mind; it is something that makes experience by arranging sensations.

And so we are not surprised when a physicist invents a potential energy to account for something that appears to arise out of, or passes into, nothing, and when his invention works out and leads to discoveries and practical applications. He acts upon nature because he has sensory data and "categories of the understanding"—mental operators, we shall say—that deal with sensory data. It is because he acts that he has a mind, for the latter is the expression of his action. Since the law of conservation is a means of action, it follows, of course, that operations based upon it—that is, potential energies, ether, electronic systems, etc.—must "work" or have "pragmatic value."

The second law is quite different: it has nothing at all *a priori* in it, as it is simply the résumé of our experience. It tells us that entropy always increases when anything happens, and that means, for our present purpose at least, that water does not run up hill, a cold poker in a cold fireplace does not become red-hot, chairs and tables do not "levitate," etc. We can imagine all these things happening, and if we think about it we do not see why they should not happen, except that they never have done so in our experience. With this observation, however, we defer the discussion of the second law till a later chapter.

CHAPTER IV

THE SOURCES OF ENERGY

It is clear that the animal has a double relationship with its environment. On the one hand it becomes aware, by means of its sense organs, of the changes that occur in the outer world. Events may happen there that menace it, and so there are places and things that are to be avoided; while other things present advantages—food and shelter, for instance—and these things it must seek and utilise. As the result of sensation and perception it acts upon the external world: its second relation to the latter.

This acting involves mobility of body and limbs—that is, the performance of mechanical work—and we have next to enquire into the source of this kinetic energy, or *vis viva*, of the animal body. Common experience shows that it is obtained from the food that the animal eats, and so we regard this food as a store of potential energy which becomes transformed into the movements that make up the locomotory, defensive, and aggressive actions. The whole series of energy transformations falls into three stages: (1) The digestion, assimilation, and distribution of food material; (2) the oxidation of the assimilated food substances, with the liberation of the bound energy contained in it; and (3) the excretion of the products of the process of oxidation. All this train of changes undergone by the substances that are taken into the animal body, built up to form its tissues, oxidised and excreted, is called *metabolism*.

The Inanimate Engine.—Now it will help us greatly in our study of the animal mechanism if we discuss first the way in which energy is transformed in the inorganic engine. In the most common form of the latter, the steam engine, there is a working substance, the water, which is heated in the boiler until it forms steam under pressure. This steam is admitted into a cylinder, where it is allowed to expand, thus forcing out the piston, and so doing mechanical work. It is again expanded in intermediate and low-pressure cylinders, thus doing more work, and by the time it has entered the condenser, and attained

the temperature of the circulating water there, it has parted with all the energy which is available under the circumstances in which the steam engine works. The condensed steam is then returned to the boiler, reheated, and the cycle of operations recommences. Note that there is a source of energy contained in the coal, and that this energy is converted into heat, which is the kinetic energy of the molecules of steam. With each quantity of steam that leaves the boiler and enters the cylinders a certain quantity of energy is taken from the source (or coal) by the working substance (or steam), and some of this is given up to the condenser (for the water circulating in the latter becomes heated). But much more energy is taken from the source than is imparted to the condenser, and the difference is represented by the mechanical work done by the engine. Thus, of the total heat generated in the furnace a certain fraction becomes transformed into the kinetic energy (or mobility) of the engine.

The Animate Engine.—Life in general—that is, plant and animal life—presents a series of events similar to that just described. There is a working substance which is represented by the very simple chemical compounds, water, carbonic acid, and certain mineral nitrogenous salts (which we shall call "nitrate" for short). These things correspond to the water employed in the steam engine. There is a source of energy corresponding to the heat generated in the steam boiler; this is the energy radiated by the sun (solar radiation we shall call it). Just as the burning coal imparts energy to the working substance of the steam engine, so the solar radiation enables green plants to manufacture carbohydrates, fats, and proteids from the water, carbonic acid, and nitrate supplied to them by the atmosphere and soil. Solar radiation acting through the green plants imparts energy to the working substance of life.

The latter, in the form of carbohydrates, fats, and proteids, all of which substances contain large quantities of chemical energy, is then eaten by the animal organism, and, after the digestive changes, incorporated in the tissues of its body. In the course of the metabolic changes which it undergoes its energy becomes transformed. Steam at a high temperature (and with high intensity of energy) enters the cylinders of the inanimate engine, and leaves the condenser at a relatively low temperature (and thus with low intensity of energy). In much the same way the life working substance enters the animal body while con-

taining much free chemical energy, and leaves it in the form of the excretions while containing almost no free chemical energy. In the steam engine the difference between the quantities of energy possessed by the working substance when entering and leaving the mechanism is represented by the mechanical work done and the heat lost by radiation, etc. Similarly, the difference between the energy of the working substance (as the food) when it enters the animal body and when it leaves it (as the excretions) is represented by the mechanical work done by the animal, and by the heat radiated away from its body and lost in the excretions.

The working substance, now degraded in respect of the energy it contained, is taken up again by the green plants, reconverted into carbohydrate, fat, and proteid, and the cycle of operations recommences.

The Digestive Process in Animals.—In the meantime, we consider only the animal part of the life energy cycle. The food matters exist, and the animal obtains these by the exercise of its sensori-motor organs. But these food matters must be digested, distributed to the tissues of the body, assimilated, oxidised, and then excreted. It is this train of events that we have now to study.

Why must they be digested? The foodstuffs must enter into the blood-stream of the animal that eats them, and in order that this may happen they must be dissolved. Now, as a rule, the food of an animal is a complex and heterogeneous collection of substances, how complex every healthy man and woman knows. In the animal living in the wild it is even more complex, since such creatures usually hunt down, kill, and devour other animals, and often ingest flesh and bone, fur, feathers, scales, hair—the edible as well as the inedible parts, which latter civilised man tries to reject in the processes of the preparation of his food. But even when the latter is carefully prepared and cooked it still contains inedible parts—the cellulose or woody fibre of vegetables, fruits, cereals, peas, and other plants, and the fibrous substance of meat and certain fats which are not easily dissolved. All these inedible constituents of the food are excreted in the fæces, and, of course, they vary in different animals: thus herbivores can digest cellulose, while man cannot as a rule.

Trituration, or mechanical disintegration of the substance of the food, occurs mainly in the mouth. Finely divided particles

are thus produced, so that the digestive juices may act all the more easily. These digestive juices play the principal part in the reduction of the food into such a form that it can enter the blood-stream, and we must say something about them. There are certain **glands** in connection with the alimentary canal (the mouth, œsophagus, stomach, and intestine), and their function is to elaborate liquids which issue from them through ducts, and are conveyed into the cavities of the mouth, stomach, and intestine. The salivary glands in the mouth secrete saliva, the gastric glands of the stomach manufacture an acid liquid called gastric juice, the liver prepares the bile, and the pancreas the pancreatic juice. All along the intestines there are glands which also secrete a digestive juice.

These various juices are active in virtue of certain mysterious substances called **enzymes** (or ferments) which they contain. The saliva contains *ptyalin*, the gastric juice *pepsin*, the pancreatic juice *trypsin*, and the intestinal juices *erepsin*, etc. The bile secreted by the liver is active mainly in virtue of the alkaline substances that it contains, and the juices of the intestine contain a substance called *enterokinase*, which " activates " the erepsin. What these enzymes are we do not know in the least, for they have never been prepared in a pure condition, and they are present in their respective juices in very small quantity. But we know a very great deal about what they do, and there are many inorganic substances which have very much the same properties, so that we cannot say " for certain " that the digestive enzymes are, in any way, substances that are exclusive to the living organism.

The Foodstuffs.—To understand their modes of operation we must consider the chemical composition of the foodstuffs. Anything that we eat consists of a mixture of substances called proteids, carbohydrates, and fats. White of eggs (albumen) is a nearly pure form of **proteid** containing much water. The lean flesh of all animals is mainly proteid, while the substance of peas, beans, lentils, cheese, and parts of the cereals and of the solids of milk are proteid in nature. **Carbohydrates** are represented by cane-sugar and glucose, the starchy foods, such as rice, the substance of potatoes, the main constituents of cereals, the sugar of milk, etc. **Fats** are the fatty parts of flesh meat and the massive fat that occurs in most animals, the cream of milk, butter, margarine (which is now mainly " hardened " or " hydro-

genated" vegetable oils, plant oils such as olive, cotton-seed, palm, etc.).

Proteids are innumerable, and the flesh of almost every species of animal contains distinct kinds. They are the most complex of all chemical substances, and it is only during the last quarter of a century that they have been successfully investigated (mainly by Fischer and the German chemists of his school). All of them contain the chemical elements carbon, hydrogen, oxygen, and nitrogen, united together in a very complex way. They are now known to be built up of peculiar substances called *amino-acids*, and one of the simpler examples of the latter has the following formula and name:

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix}{>}CH{-}CH_2{-}CH(NH_2){-}COOH.$$

Leucine or a-amino-iso-caproic acid.

Very many of these amino-acids are known, but many more still have yet to be investigated. Now imagine a number of these united together in this way:

$$\begin{array}{ccccccccccc} & & R' & & & & R'' & & & & R''' \\ & & | & & & & | & & & & | \\ NH_2 & — & CH & —CO—— & NH & — & CH & —CO—— & NH & — & CH—COOH. \\ & & (1) & & & & (2) & & & & (3) \end{array}$$

Here we have a *chain* of members, each of which has the form:

$$\begin{array}{c} R \\ | \\ —NH—CH—CO—; \end{array}$$

the N, H, C, and O each represent an atom of nitrogen, hydrogen, carbon, and oxygen respectively; and R represents a complex "radicle" or group of atoms such as (in a simple case):

$$CH_3{-}CH_2{-}CH_2{-}.$$

In the example we have given the chain consists of only three members, but there may be very many more. It may be bent round to form a ring, and the ring may be joined to other rings, and there may be "side chains" attached in various ways. Now compare all this with the chemical formula of urea (which is the characteristic substance present in the urine):

$$OC{<}\begin{matrix} NH_2 \\ NH_2 \end{matrix}$$

and we get an idea of the exceedingly complex chemical structure of the proteids—a structure upon which, in some way or other, the phenomena of life depend. Proteids are therefore combinations of amino-acids, and they contain, generally, about 16 per cent. of nitrogen.

Carbohydrates contain carbon, hydrogen, and oxygen, but no nitrogen. They are also very complex chemical substances; thus "grape-sugar" (dextrose, or glucose) has the formula:

$$CH_2OH—CH(OH)—CH(OH)—CH(OH)—CH(OH)—CHO.$$

Many other sugars are more complicated, and the starches and gums are more complicated still.

Fats are still more complicated in chemical structure than the carbohydrates. What we usually call an "oil" or a "fat" is a combination of one or more *fatty acids* with glycerine. A fatty acid consists of carbon, hydrogen, and oxygen atoms united together to form a chain; thus stearic acid is:

$$CH_3—CH_2—15 \text{ other } CH_2 \text{ links}—COOH,$$

and may be written in short by R—COOH, where the R stands for the chain CH_3—CH_2— to seventeen terms. Now three molecules of stearic acid combine with glycerine to give us—

$$\begin{array}{l} R—CO—O—CH_2 \\ \qquad\qquad\quad\ | \\ R—CO—O—CH \\ \qquad\qquad\quad\ | \\ R—CO—O—CH_2 \end{array}$$

which is *tristearin*, the principal constituent of mutton fat. Since there are a great number of different fatty acids there must also be many kinds of fats.

Now all this seems very technical, but it must be clearly understood that no one can hope to get even a slight acquaintance with the mechanism of life without a knowledge of at least such detail as we have set out above. And, after all, it is not very difficult!

What we eat is therefore a mixture of proteids, carbohydrates, and fats. The proteids, especially when cooked, are insoluble in water, and so are the fats. We can take cane-sugar, and other sugars, into the alimentary canal, but they must be converted into dextrose before they can be used by the tissues. The starches which form the bulk of potatoes, rice, and similar foods, as well as a large part of cereals and the breads that are made from these

things, are also insoluble, and they must be converted into dextrose. Digestion consists, therefore, of the solution of the proteids and fats, and the conversion of the starches and other carbohydrates into dextrose.

As soon as food enters the mouth digestion begins. The salivary enzyme, ptyalin, acts on the starchy substances, converting them into sugar, and in the stomach the pepsin of the gastric juice acts upon the proteids. The fats are not touched at all until the food enters the duodenum, and then the main digestive operations begin. The trypsin of the pancreatic juice and the erepsin of the intestinal juice act energetically on the proteids, carbohydrates, and fats, and the bile secreted by the liver aids in a way that we cannot explain here. The result of the action of all these enzymes is that the proteids are split up into their constituent amino-acids, the starches are converted into dextrose, and the fats and oils are split up into fatty acids and glycerine. Now all these substances are soluble in water (or at least in the liquid bathing the internal walls of the alimentary canal), and so they can soak through into the blood. These substances—amino-acids, fatty acids, dextrose, and glycerine—are what the animal organism wants—they are its proximate food principles.

Absorption and Distribution.—They must get into the bloodstream and be carried to the muscles, glands, and other tissues of the body. How? That leads us to consider the organs of circulation. Everywhere in the body there are minute bloodvessels, called *capillaries*, forming a close network, and along with these there is a separate system of vessels called the *lymphatics*. We do not consider the latter here, except to say that ultimately they communicate with the bloodvessels.

We regard the bloodvessels (from our point of view of the distribution of nutritive matter) as beginning in the walls of the alimentary canal. There the capillaries form a very close network just within the internal lining (the mucous membrane), and the liquids in the alimentary canal are separated from that in the capillaries by the mucous membrane, some very loose connective tissue, and the very delicate walls of the capillaries themselves. So it is easy for the digested, soluble food substance to soak through the mucous membrane, the loose submucous layer, and the walls of the capillaries. Now the "soaking" through is not the same process as the soaking of a few drops of

soup through a piece of porous blotting-paper; in the latter case the liquid soup goes through unchanged, except for the solid particles, which are kept back by the blotting-paper, while the living cells of the mucous and other membranes act on the digested food matters. We have seen that the digestive enzymes change the composition of the proteids thus:

$$\text{Proteids} \longrightarrow \text{amino-acids.}$$

But the same enzymes are contained in the cells of the mucous and other membranes, and as the amino-acids pass through

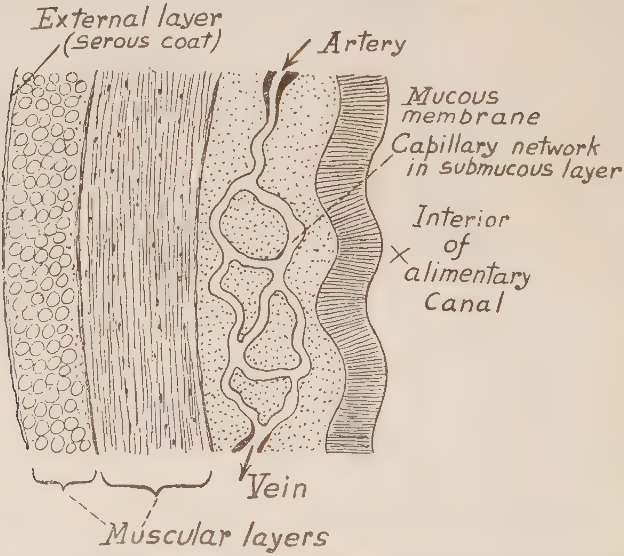

FIG. 12.—PART OF A TRANSVERSE SECTION THROUGH THE WALL OF THE INTESTINE. VERY DIAGRAMMATIC.

they are again acted upon by the enzymes thus:

$$\text{Amino-acids} \longrightarrow \text{proteids.}$$

Thus the activity of the enzymes is reversible. Now it is no use presenting all this to the reader as a finished picture of the processes of digestion and absorption of the food substances, for we have only the vaguest notion of what is the nature of the reversibility; one thing is, however, certain—the proteids are split up into amino-acids in the cavity of the alimentary canal, and as these substances are soluble they can pass through the intestinal wall into the capillary blood-stream. In passing into

the tissues which utilise them, the same enzymes now reconvert the amino-acids into proteid. But the proteid is now a different one (or ones), for the amino-acids have been rearranged.

Somewhat similar rearrangements take place in respect of the fats.

The blood circulating in the intestinal wall thus becomes charged with proteid, fat, and carbohydrate, all three classes of substances being now thrown into forms which are "native" to the body of the animal in which the digestive process occurs. One eats the proteids characteristic of beef, mutton, pork, fowl, fish, etc., but all these become converted somewhere into human proteid, and all the different fats that one eats are similarly converted into human fat. That is, the processes of digestion, absorption, and assimilation are a laborious and roundabout series of chemical conversions which make up a large portion of our vital activity, and which might be shortened with much advantage.

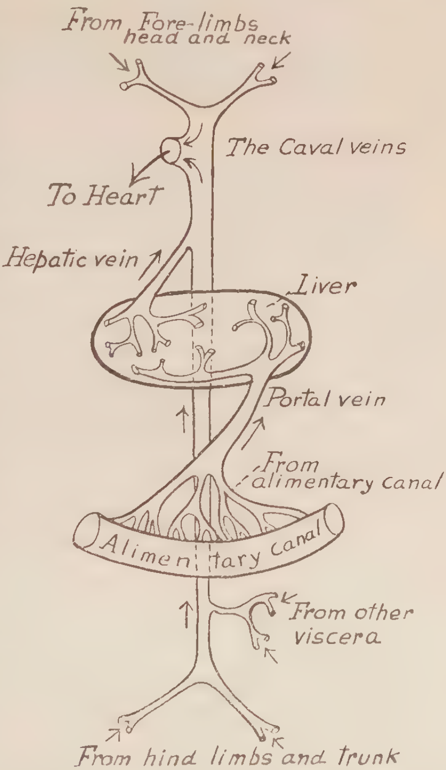

FIG. 13.—DIAGRAM OF THE GREAT VEINS IN THE BODY OF A MAMMAL.

Little by little the capillaries in the walls of the stomach and intestine unite together to form veins, and the smaller veins unite further until one large vessel—the *portal vein*—drains away all the blood circulating in the alimentary canal from the stomach backward. This great vein carries the intestinal blood, laden with nutritive substance, to the liver, and there it divides up again into small and smaller veins, and these finally break up into capillaries which ramify among the cells of

the liver. Something is done to the blood there, and then the capillaries reunite into veins and then into another great vessel —the *hepatic vein.*

At the same time the blood which has been circulating in the capillaries of the muscles of the hind-limbs and trunk, in the kidneys, reproductive organs, spleen—in short, in all the body behind the upper limbs—is gathered up into a vein called the *posterior vena cava*, and this is joined by the hepatic vein. All the blood that has been circulating in the fore-limbs, the chest, head, and neck is collected by two veins called the *anterior venæ cavæ.* Finally, all three caval veins unite and pour their blood into the heart.

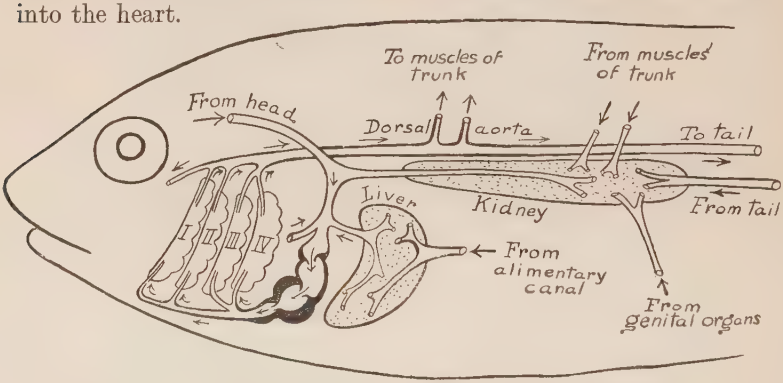

FIG. 14.—DIAGRAM OF THE BLOODVESSELS OF A FISH.
i, ii, iii and iv are the gills.

Thus there is a vascular system, which consists of a series of veins returning all blood that has been circulating anywhere in the body to the heart. Clearly there are at least two kinds of blood in the veins: (1) That which has been circulating in the muscles, and which has, therefore, been depleted of some of its nutritive properties; and (2) that which has been circulating in the intestine, and which has become enriched with substances of nutritive value. Now we have to consider the other half of the blood vascular system—the arterial vessels which distribute this nutritive substance received from the alimentary canal (*via* the liver) to the body at large.

First of all we look at the arterial vessels of a fish (for here the conditions are very simple). Much the same kind of venous system is present in the fish as in man (or at least we need not worry about the minor differences), but the arteries are not complicated by the presence of lungs.

The fish respires by taking oxygen into the blood through the gills, and also by giving out carbonic acid in the same way (we return presently to this respiratory process, and only consider just now the path of the blood). In the fish, then, the heart is a fairly simple organ consisting of two main chambers, the auricle and the ventricle. Each of these is a muscular, hollow organ which expands and contracts rhythmically. The blood which has returned from the body *via* the caval veins is poured into the auricle, which then contracts. There are valves at the entrance to the auricle and others at the opening of the latter

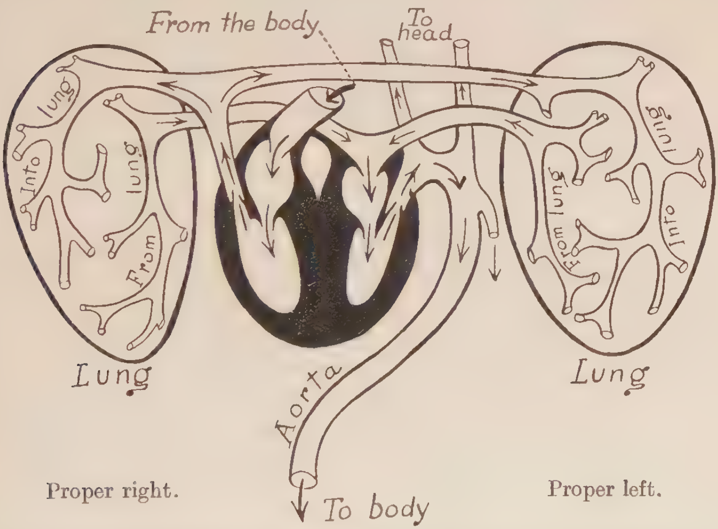

FIG. 15.—THE CONNECTIONS BETWEEN THE HEART AND THE LUNGS IN A WARM-BLOODED ANIMAL.

into the ventricle, and these structures so act as to prevent the blood from being forced back into the caval veins, but they allow it to flow into the ventricle. There are valves at the opening of the ventricle into the *aorta* (that is, the great artery that springs from it), and these act so as to allow the blood to pass through the aorta when the ventricle contracts. Thus the contractions and dilatations of the heart send the blood in one direction only—from the caval veins into the aorta.

From the latter vessel it goes to the gills, where the arteries break up into networks of minute capillaries. Then the latter vessels reunite until they form several large arteries, two of

which go to the head, several to the "shoulders" of the fish, and one runs down the body just underneath the backbone and supplies the viscera and the muscles of the body and tail.

Thus there is a fairly simple and complete circulation in the fish. The blood is propelled by the heart into and through the gills, and then it is distributed through the arteries to all parts of the body. Having traversed every part of the latter, it returns to the heart again *via* the great veins.

The reader will now easily understand the main scheme of circulation in the warm-blooded animals, including man. Here we have a double heart, one half of which (the right one) is connected with the lungs, and the other (left) half with the rest of the body.

Tracing out the paths taken by the blood-stream, we will see that the caval veins discharge into the right auricle, which contracts and sends the blood into the right ventricle. From there it goes through the pulmonary arteries into the right and left lungs, and having traversed the capillaries in these organs, it is returned to the left auricle by the pulmonary veins. The left auricle forces it into the left ventricle, and from there it is propelled all over the body, being distributed by the great aorta and the arteries that branch out from the latter.

The first complete demonstration of the circulation of the blood must have appealed to physiologists as a perfect proof of the mechanical conception of life. This proof, however, was slow in coming, and many men contributed to it. Servetus, a scholar of the early sixteenth century, seems to have discovered the pulmonary circulation, and, curiously enough, he announced it in 1553 in a theological work called *De Restitutio Christianismi*, for the publication of which he was hunted out from Spain by the Inquisition, only to encounter the intolerance of Calvin at Geneva, where he was burned. The English physician Harvey discovered the other, or systemic circulation, and gave a complete and formal demonstration of the whole scheme in 1628. Fabricius had already discovered the valves in the veins, and in 1661 Malpighi found the connection between arteries and veins—the innumerable, minute, hairlike vessels called the capillaries—and that completed the proof. But even before the latter discoveries the great mind of Descartes had made use of the incomplete demonstration of Harvey to establish his con-

ception of an automatic, mechanical, animal body, and no such momentous contribution to a working hypothesis of life had before then, or has since, been made.

The Respiratory Interchange.—Thus food materials are taken into the alimentary canal, digested, and transferred to the blood-stream in such a form that they can be assimilated by the tissues. They are then distributed in the blood-stream to all parts of the body.

But simultaneously there is an interchange of something between the blood itself and the air that is inspired by the lungs. Here we mention, for the first time, the arterial and venous kinds of blood. That which issues from a cut vein, and in general from a slight wound, is blood that is rather dark red in colour, and which *oozes* out from the cut vessels, whereas that

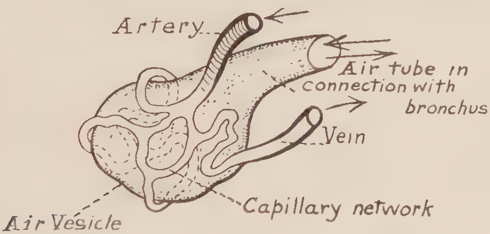

FIG. 16.—AN ALVEOLUS, OR AIR SAC, FROM THE LUNGS, WITH ITS BLOODVESSELS. HIGHLY MAGNIFIED.

which comes from an artery is brighter red in colour and it flows out in pulsations. Examining these bloods, physiologists have found that that flowing in the arteries contains more oxygen and less carbonic acid gas than that flowing in the veins. Examining the air that is inspired, they find that this contains the usual 21 per cent. of oxygen and about $\frac{1}{40}$ per cent. of carbonic acid, while the expired air contains only about 16 per cent. of oxygen and about 4 per cent. of carbonic acid.

Both the composition of the blood and that of the air are changed in the lungs. Now look at the structure of the latter: each consists essentially of an immense number of air vesicles surrounded by capillary bloodvessels.

This is a scheme of the essential structure of the lung. The trachea divides to form the two bronchi, and the latter divide and subdivide again and again until they terminate in multitudes of sacs, or vesicles, one of which the greatly simplified figure

represents. The pulmonary artery (carrying *venous* blood) enters the lung. and also divides and subdivides again and again until, in the end, each ultimate twig of the artery breaks up into a network of capillaries on the outer wall of an air sac.

Air is drawn up into the lungs and expelled out from them by the upward and downward movements of the diaphragm (the muscular partition between the chest and abdominal cavities) in men, or by upward and downward movements of the ribs and chest wall in women. Thus the sacs are full of air which is continually being renewed (we do not really draw air right down to the " bottom " of the lungs, but into the upper parts only). The air of the smallest sacs renews itself, however, by diffusion into the fresh air that is continually entering the larger passages. Now the venous blood that enters the air-sac capillaries contains (in solution) less oxygen and more carbonic acid than that which

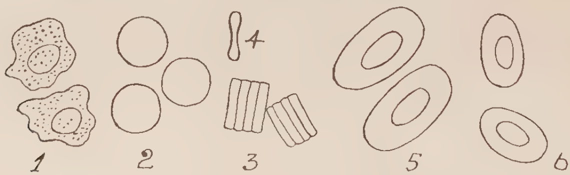

FIG. 17.—BLOOD-CORPUSCLES.

1, White; 2, human; 3, human in " rouleaux "; 4, human, seen from the side; 5, from a frog; 6, from a fish.

is contained in the air of the sacs, and therefore an interchange occurs such that oxygen goes through the very delicate membrane of the sac and the equally thin wall of the capillaries from the air into the blood, while carbonic acid gas passes from the blood into the air.

In respiration, then, we take oxygen from the outer air and transfer it to the blood-stream, and we take carbonic acid from the blood-stream and transfer it to the air. And so the venous blood, which goes to the lungs and comes from the body, contains more carbonic acid and less oxygen than the arterial blood, which comes from the lungs and goes to the body.

Just a word as to how the oxygen and carbonic acid are carried by the blood. The latter, when seen under the microscope, becomes a clear, colourless liquid in which there are enormous numbers of minute, biscuit-shaped bodies called the red blood-corpuscles.

These contain a chemical substance called hæmoglobin, which carries the oxygen, while the carbonic acid is carried by the clear liquid part of the blood, or plasma. In all animals there are other corpuscles which are colourless, and some of these are called *phagocytes* (devouring cells) because they have the power of ingesting foreign substances, such as bacteria, which may enter the blood. The pus which forms when an abscess gathers consists largely of phagocytes. They are a protection against infection.

We have now seen how the nutritive materials—the proteids, fats, and carbohydrates—and the oxygen which is to "burn" them, are obtained, and how they are carried to the tissues.

The Sources of Energy.—These proteids, fats, and carbohydrates, digested, dissolved, split up, and recombined, are the immediate sources of energy (the ultimate source is, of course, the solar radiation, which enables the green plants to synthesise water, carbonic acid, and nitrate into proteid, fat, and carbohydrate). They contain potential, chemical energy which is at a high intensity, and is available for doing work.

How ? In the inanimate engine there is a working substance, the steam, and we regard this as something different from the engine, which may exist even if there is no steam in it. But in the animate engine the mechanism (muscle and nerve) are the same as the working substance (the proteids, fats, and carbohydrates, which *are* the muscle and nerve). It *may* be the case that a "living" muscle contains "non-living" substances which are oxidised and yield energy, but since we only define the "life" of the muscle by its irritability (that is, its ability to contract when it is stimulated), we cannot be sure that there are parts of it which are not alive. It is probable that the substances carried to the muscle by the blood-stream are actually built up into the living tissue—they become alive—and are then oxidised, or die.

Further, the inanimate engine—steam, gas, or petrol—is a thermodynamic machine. It contains a working substance—steam at a temperature, say, 120° C., or a mixture of gases resulting from the explosion of gas and air, or petrol vapour and air at a temperature of, say, 700° C. to over 1,000° C. At these high temperatures the molecules of the gases are moving with enormous velocities, and so they exert pressure. Therefore a heat engine is a mechanism which converts the kinetic energy of

a gas at a relatively high temperature into the kinetic energy of a material structure (pistons or turbines) at a relatively low temperature.

It may be that the muscle of an animal is a heat mechanism of this kind—a thermodynamic machine—but it is not likely, and it is far more probable that the muscle contracts because the chemical energy of the proteids, fats, and carbohydrates is transformed into mechanical work without passing through the stage of heat. There are physical mechanisms that do this. A galvanic battery may produce a current of electricity, and the latter may work an electric motor and no heat at all (or only a trace of it) may be generated. Here chemical energy (that of the zinc and acid in the battery) transforms into electricity, and the latter does mechanical work in the motor. Now all that we can state positively about the events that happen when a muscle contracts are these: there are complex, chemical compounds in the protoplasm of the muscle which break down (or " explode "). Very complex molecules thus dissociate into relatively simple ones, and the energy that held these complex molecules together is liberated and is transformed into the mechanical work done by the muscle when it contracts against a resistance.

But it is quite certain that heat is also generated—that everyone knows who becomes warm when he does hard muscular work. Now, is this generation of heat a necessary step in the doing of bodily work ? In cold-blooded, wholly aquatic animals it is not certain that heat is produced, or, if it is, it is only in very small quantity. A warm-blooded animal preserves a constant temperature, which is usually considerably higher than that of its environment, and so it must generate heat. And it is probable that this heat is produced by the oxidation of the relatively simple molecules into which the complex protoplasmic substance breaks down. These products of dissociation are oxidised into water and carbonic acid.

Protein-containing tissues break down into the same products, and also into simple nitrogenous substances that later on become urea in the liver and kidneys—that is, into such substances as can easily be removed from the muscle in solution in the circulating blood.

The Removal of Waste—Glandular Activity.—In the heat engine the working substance—steam in the steam engine, or the products of the explosion in the internal combustion motor—

loses its available energy and must be removed. The steam is passed out from the condenser, and is returned to the boiler to be reheated, and the cylinder gases in the gas engine are blown out into the atmosphere. So also in the animate engine the working substance loses its available energy: protoplasmic substances disintegrate into simpler ones, which are then oxidised to form carbonic acid and water. These latter compounds, with the urea, which is the end product of the disintegration of the nitrogenous part of the protoplasmic substance, must be removed from the animal body.

So we must say a word or two about *excretion*. The water which appears in the muscles as the result of the disintegration

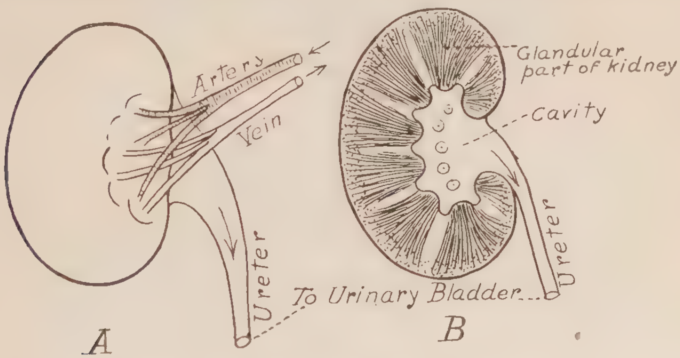

FIG. 18.—THE KIDNEY OF A MAMMAL.

A, The organ with its bloodvessels and duct; *B*, the kidney cut through longitudinally.

of the protoplasm, or of the oxidation of the products of disintegration of the latter, simply oozes through into the bloodstream, and the carbonic acid similarly produced is also taken up by the blood. The effect of work done by the body is therefore to add water and carbonic acid to the blood, and so the latter becomes changed, "impure," or venous. As it streams through the capillaries in the lungs the carbonic acid is excreted, passing out into the expired air, while, at the same time, some of its excess of water also passes out in the same way.

But most of the water, and also the urea, is excreted by the kidneys. Consider first of all the urea. The proteid substance of the muscles is, as we have seen, continually disintegrating into simpler substances, giving up energy as it thus breaks down. These products of metabolism are not yet urea, but they are

carried to the liver, where they are converted into this latter substance. The blood circulating in the body therefore contains a certain small proportion of urea. This is the waste product of nitrogenous metabolism; it has no useful function, and it must be removed from the system.

We consider the kidneys in some detail, because they may be taken as types of glands, structures which we have not, so far, described.

Each of them, then, is an organ provided with (1) an artery carrying blood into it from the aorta; (2) a vein carrying blood away from it into the posterior vena cava; (3) a duct, the ureter, which carries away the water and other substances taken from the blood that flows into the gland; and (4) nerves. When in action, blood containing urea and other waste substances, as well as an excess of water, is continually flowing into the kidneys through the renal arteries, while the same blood deprived of these waste substances and of a certain quantity of water is continually flowing out through the renal veins. Water containing the urea, etc., gathers in the cavities of the kidneys and slowly trickles down the ureters into the urinary bladder, from which it is periodically expelled. The nerves that enter the kidney go to the arteries, and they act by exciting the muscles in the walls of these vessels to expand or contract, thus altering their calibre, and so increasing or diminishing the quantity of circulating blood. If the calibre of the renal veins remains the same, the blood-pressure of the kidneys increases, and so the secretion of

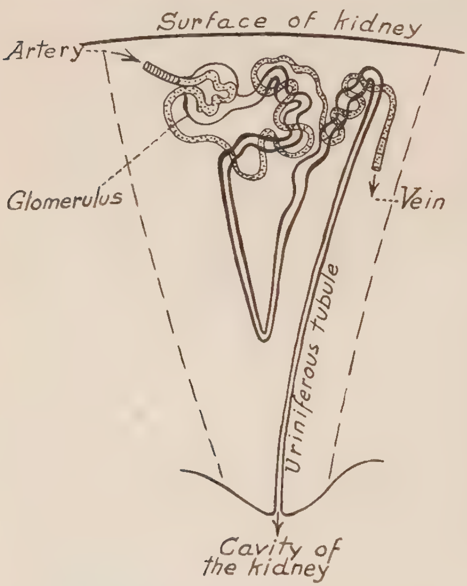

Fig. 19.—One of the Secretory Units (or Uriniferous Tubules) of the Kidney represented in a very Diagrammatic Way. Magnified.

urine increases, and *vice versa*. Thus the secretory activity of the kidneys can be regulated. Similar regulatory mechanisms exist everywhere over the animal body, and the nerves mainly responsible belong to what is called the sympathetic nervous system.

Now look at the minute structure of the kidney. Here we represent, very simply, and on a much bigger scale than the natural one, one of the tubules that excrete the water, urea, etc. First of all the blood in the renal artery becomes distributed through a multitude of branches or twigs of this bloodvessel, and we may regard each twig as going to a peculiar structure called a *glomerulus*.

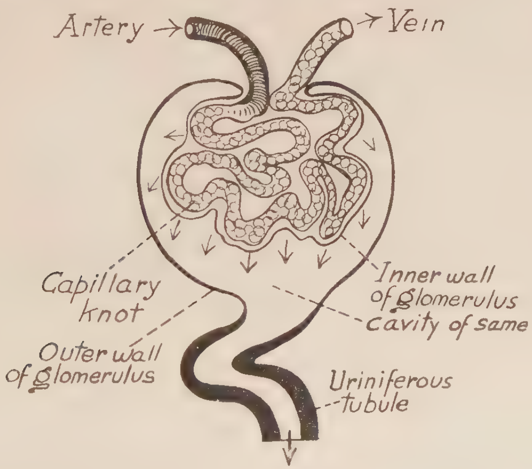

FIG. 20.—THE GLOMERULUS OF A URINIFEROUS TUBULE, WITH ITS BLOODVESSELS. HIGHLY MAGNIFIED.

This glomerulus is like a bulb at the end of a uriniferous tubule. One part of the bulb is pushed in, and a twig of the renal artery enters and breaks up into a little complex knot of capillaries, from which a twig of the renal vein gathers up the blood and takes it away. This little twig of the renal vein again breaks up into capillaries, which surround the rest of the uriniferous tubule, as shown in Fig. 19. Thus we see a rich blood-supply carried by capillaries surrounding the parts of the gland that secrete. Water is secreted from the blood in the capillaries of the glomerulus, and this water oozes through the inner wall of the bulb, and so goes into the uriniferous tubule. Then the cells of the latter take urea, etc., from the blood in the capillaries that sur-

round them, and these waste substances go with the water into the cavity of the kidney, and so down the ureter into the bladder.

Note that the essential things in this mechanism are the cells of the walls of the glomerulus and tubules. It is these cells that have the power of taking water, urea, hippuric and uric acids, etc., from the blood; but they do not take sugar, albumen, or other things. If they do (as in diseased kidneys), that is not their proper function, and the organ assumes an individuality that is harmful to the organism—a disharmony is established. How exactly the cells of the normal kidney function in removing waste substances and nothing else we do not know.

This is a type of glandular activity, and there are numerous other organs in the body that do analogous things. The gastric glands secrete hydrochloric acid and pepsin into the stomach; the pancreas secretes a mixture of ferments or enzymes called trypsin; the glands of the mouth secrete saliva; those of the skin secrete sweat, water, oil, etc. (all waste substances), and so on. In all these cases there are tubular mechanisms (as a rule much simpler than those of the kidney), and these are provided with nerves and arteries and veins in much the same way. There are also ducts, tubes which carry the products secreted by the glands to the places where they are wanted, or *via* which they are eliminated from the body.

But there are *ductless glands* also. Such are the thyroid, the thymus, the pituitary, and pineal glands (see p. 99), and the adrenal glands. In such cases we have glandular cells surrounded by capillaries, but there is no duct and there is apparently no secretion. We know, however, that there is a secretion, and that this goes into the blood itself, and is then carried to the rest of the body. These ductless glands are of enormous importance in many ways.

The reader will miss the true understanding of vital activity if he does not note the character of unification of activity that is implicit in our conception of the animal mechanism. This chapter and the last one deal with mechanisms: the sensori-motor system—that is, sensory organ connected with motor organ; the mechanism of alimentary canal and glands that converts the crude food substances into the specific proteids, fats, and carbohydrates that are required by the animal tissues as sources of energy and means of growth; the apparatus of circulation that distributes these substances; the respiratory mechanism that

obtains the oxygen that must be distributed along with the foodstuffs; and the excretory organs that remove the degraded food substances and expel them from the body. It has been necessary to consider these things separately, but that is only our method of analysis of a single phenomenon, and it must be repeated that all these activities are co-ordinated and are really one. Nothing in the way of mechanisms that we can make or devise exhibits the unification of activities expressed in the life of a normal animal. The modern State—which has, rather foolishly, been called an organism—is said to represent the greatest achievement of men, but no one can attempt to analyse its activities dispassionately, as we have analysed those of the living animal, and see in them anything other than a tissue of disharmonies. The scientifically organised State has still to come into existence. Think of the distribution of foodstuff to the functioning animal body. In severe manual work the bloodvessels of the muscles dilate so as to permit of a more abundant supply of nutritive material and oxygen, and a rapid removal of waste products. In intensive mental work the blood-supply to the brain is similarly speeded up. In digestion the same thing occurs with relation to the intestinal circulation. Such regulations are as yet hardly at all evident in the activities of the modern State.

CHAPTER V

ON VITAL PRODUCTION

We have now traced the working substance of life through the transformations which it undergoes in the animal body. These are as follows:

Animal Metabolism.—(1) Certain food substances contain the working substance in the form of a mixture of proteids, fats, and carbohydrates, derived from the tissues of animals and plants. This mixture is taken into the alimentary canal, where it is digested and dissolved. As the result of the processes of digestion and absorption the proteids, fats, and carbohydrates of the food are made similar, or assimilated, to those substances such as they occur in the body of the animal that eats them.

(2) They are then distributed by the blood-stream and incorporated in the protoplasm of the muscles and other tissues.

(3) These protoplasmic substances are disintegrated into simpler chemical compounds, with the result that energy is liberated.

(4) The products of the disintegration of the substances of the tissues are finally oxidised and excreted.

The result of these metabolic processes is that the working substance becomes degraded energetically and chemically. Let us take the energy transformations first. An ordinary day's diet is likely to contain about 125 grams of dry proteid, 125 grams of dry fat, and 400 grams of dry carbohydrate,* and if the heat value of these quantities of dry foodstuff be found it will add up to about 3,500 calories. Now the result of the chemical transformation undergone by this average quantity of food is that a certain quantity of carbonic acid and water is excreted by the lungs and kidneys, and about 42 grams of urea by the kidneys. The water and carbonic acid contain no free (or available) energy, but the urea contains about 105 calories. Therefore about 3,390 calories of the energy contained in the food is utilised by the body. About 12 to 30 per cent. of this

* In British weights about 4½ ounces of dry proteid, 4½ ounces of dry fat, and 14 ounces of dry carbohydrate.

energy is transformed into mechanical work done by the muscles of the body and limbs, and the rest is transformed into heat. That is the energy transformation.

Assume an adult animal in perfect health and of stationary weight; then the working substance enters the tissues in the form of proteid, fat, and carbohydrate, and leaves them in the form of water, carbonic acid, and urea. That is the chemical transformation. Looked at both from the point of view of available energy and that of chemical structure there is degradation. First, in that a high intensity of chemical energy becomes a low intensity; and, second, inasmuch as complex chemical compounds become simple ones.

The working substance of life is now water, carbonic acid, and urea. Let us trace its further history. The water and carbonic acid undergo no further change (just yet, at all events). But the urea (and the other proteid degradation products) do.

The Fate of the Proteid Residues.—The urea (and other nitrogenous substances) contained in the urine find their way, through drains and by other means, into the water of rivers and of the sea, or on to the land, and then it is at once attacked by micro-organisms. Now a few words about the latter.

Micro-organisms are (in the present connection) bacteria, moulds, yeasts, and infusoria. The bacteria are exceedingly minute, single-celled organisms which cannot be said to be either animals or plants, since their modes of generation are altogether special. Many of them (but still a small minority) are called pathogenic organisms, and are the causes of certain infectious and epidemic diseases, such as cholera, enteric fever, pneumonia, "influenza," diphtheria, catarrh, septicæmia, etc. Being excessively minute, capable of living in water, and even of being partially dried, they may be distributed in liquids, in dust, on infected clothing, etc. When they enter a suitable "soil"—that is, a liquid containing certain organic substances in solution—they multiply at an incredibly high rate. The human body possesses certain defences against these pathogenic bacteria—that is, the phagocytes of the blood can ingest and destroy them, or the plasma can form certain substances which can neutralise their poisonous activity. If the infected animal fails to set up such adequate defences, the invading pathogenic bacteria multiply with great rapidity and form *toxins* which are injurious to one or more tissues, and so instigate a condition of disease.

Other micro-organisms have, on the whole, beneficial effects. Yeasts are the causes of the fermentations in brewing and analogous processes. Moulds and bacteria cause the ripening of cheese. Fermentative and putrefactive bacteria act upon and break down organic matter, and moulds and infusoria behave in similar ways.

Many substances that we meet with every day "go bad": milk curdles; broths, soups, etc., "go sour"; and meat of all kinds becomes tainted and then putrefies. Beers and wines may sour. In the case of meat and fish, the "ripening" (as in the case of game) and the tainting are the result of the activity of bacteria and of enzymes that are naturally present in the flesh itself. When the flesh is alive, the activity of these enzymes are inhibited in some way, but after general death of the tissues they begin to digest the flesh in which they occur. This process is called *autolysis*, or self-digestion. At first it produces savoury, and then noxious substances.

By-and-by the meat putrefies, with the production of offensive odours, and this is the result of the action of bacteria which infect the decaying substance. If this activity is allowed to go on unchecked, the offensively smelling meat begins to disappear, and by-and-by the smell itself passes away.

Any organic substances exposed to the air or contaminated with dust, "dirt," or impure water, will "go bad," ferment, or putrefy, and this is because fermentative and putrefactive bacteria gain admittance, multiply, and break down the organic matter, using the latter as a source of food. If rigorous and successful means be taken to exclude all micro-organisms from the organic matter, the latter will not go bad. Thus if milk be "pasteurised" (that is, heated for several days in succession in closed bottles to a temperature of about 80° to 90° C.), it will remain fresh and sweet for an indefinite period. If meat be sterilised by heating to over the boiling temperature of water in sealed tins for a sufficient period, it will be preserved in good condition for years. If meat be frozen to well below zero centigrade it will remain good. If salt, boracic acid, formaldehyde, chlorinated water, etc., be added to the organic substance, putrefaction will not occur. Heating to a sufficiently high temperature kills all micro-organisms, as also does antiseptic substances like salt and boracic acid. Freezing arrests the multiplication and vital activities of bacteria, but does not kill

them, so that frozen meat will putrefy if it thaws. This is the rationale of all processes of preservation of meat and other food substances: heating destroys the "germs"; salting and drying and freezing arrest their activities; and rigorous exclusion of air, dust, and other media which contain the organisms may delay or prevent the putrefaction. Filtration of water through porous earthenware keeps back the germs, and exposure to strong sunlight, or, better still, to the rays from an electric mercury vapour lamp, is said to destroy them.

The Mode of Action of Micro-Organisms.—In fermentation and putrefaction much the same chemical processes occur as when food substances are digested in the alimentary canal of an animal. In fact, the micro-organisms form enzymes similar in effect to the enzymes that are found in the stomach and intestine. The enzymes split up proteids into amino-acids and ferment carbohydrates, but the processes of disintegration of proteids and carbohydrates go much further in bacterial action than in the digestive operations. These processes are *very* complicated, and are far from being fully understood. We call the breaking-down of fats and carbohydrates by bacteria, yeasts, and moulds *fermentation*, and that of proteids *putrefaction*. Many species of bacteria, etc., are concerned in each process, and the rapidity with which the latter occurs depends on the temperature and other conditions.

The final results are quite clear and well known. In all cases, and if there is time enough, fats, carbohydrates, and cellulose, such as the vegetable substances in grains, grass, leaves, fruits, woody fibre, etc., are decomposed, with the result that their chemical substance transforms into carbonic acid and water. Putrefaction of proteid substance is accompanied or succeeded by what is called nitrification—that is, other organisms, called "nitrifying bacteria," also play their part. In the end the proteid putrefies to form ammonia compounds, and then the nitrifying bacteria oxidise the ammonia, converting this into nitrous acid and the nitrous into nitric acid. The lime, soda, and potash in the soil or in streams, rivers, etc., combine with the nitric acid to form nitrate, and this is the way in which Chili saltpetre and other natural stores of nitrate have been formed.

Thus the action of micro-organisms on all dead organic matter is to convert the latter into carbonic acid, water, and nitrate. This is, in general, the fate of the excretions of animals and of all

dead animal and plant bodies, "offal," or remains. All organic substances whatever are susceptible to bacterial action, and since micro-organisms are universally distributed in nature, in the air, soil, and in fresh and salt water, organic matter thus suffers resolution into innocuous mineral substances of very simple chemical constitution. There are certain conditions in which this bacterial decomposition of organic matter is delayed. At the bottoms of deep oceans the temperature of the sea is very little above freezing-point (or is even below the freezing-point of fresh-water), and there putrefactive action goes on very slowly. In extreme northern climates the air temperature is also very low, and dead bodies of animals are sometimes frozen in ice or in the soil, and so escape decay. In very dry climates organic matter also remains in a relatively stable condition, since the putrefactive bacteria are unable to function in the absence of water. Such is the mode of origin of many forms of guano.

But, in general, all organic matter is ultimately resolved into carbonic acid, water, and nitrate, and these substances tend to be distributed all over the earth. Carbonic acid is contained to the extent of about 0·04 per cent. in the atmosphere, and it is present in rather larger proportions in fresh and salt water. Water itself is distributed everywhere except over desert land areas. Mineral nitrogenous substances, such as nitrites, nitrates, and salts of ammonia, are also contained everywhere in the soil and in fresh and salt water, and oxides of nitrogen, capable of forming nitric acid, are formed in the atmosphere by the combination of nitrogen and oxygen that occurs whenever there are lightning discharges. But mineral nitrogenous compounds—which are the indispensable materials of life—occur everywhere in exceedingly small quantities,* and the abundance of life depends on the quantity of these substances that is available.

It is therefore convenient roughly to classify all living things into animals, bacteria, and plants. The animals *consume* proteids, fats, and carbohydrates, oxidising these substances into water, carbonic acid, and certain nitrogenous residues such as urea, uric acid, hippuric acid, etc. The bacteria act upon the nitrogenous residues, converting them into nitrate, and they also act upon dead animal and plant tissues, and upon the excreta

* Except under quite special conditions, as when deposits of "Chili saltpetre" and analogous substances are formed. Here the dry atmosphere and soil inhibit plant growth, with the result that nitrate accumulates.

of animals, resolving those substances into water, carbonic acid, and nitrate. The plants then utilise the latter substances as crude foodstuffs.

Plant Metabolism.—We have now to consider the further history of the working substance of life after it has undergone the chemical and energetic degradations that are the results of animal and bacterial metabolism. Returning to our inanimate engine, it may be recalled that the working substance, or steam, expands and does mechanical work on the pistons, and actuates the mechanism. Then it passes through the condenser, having lost its available energy. It is returned to the boiler and is heated, and so takes up fresh available energy, and the cycle of operations recommences. We take the same general view of the animate engine. The working substance, which is a mixture of fats, proteids, and carbohydrates, passes through the animal body, undergoing chemical transformations, doing mechanical work, and (it may be) heating the body. Then it passes out from the body as the excretions, having lost most of its available energy, and it is further acted upon by bacteria, when it loses the remainder. It must now be transformed so as to reacquire available energy, just as the cold water entering the steam boiler again takes up energy in the form of heat.

This absorption of energy by the life working substance is effected in the tissues of green plants, and we must now refer briefly to the metabolism of the latter.

A green plant is an organism—that is, something that transforms energy of itself, grows, and reproduces its individual form and mode of behaviour. Its growth is an obvious thing, and so it is clear that it absorbs material from the medium in which it lives. Now, with rare exceptions* the plant organism does not take in visible foodstuff—that is, we can see no obvious process of feeding, mastication, digestion, etc. We know that it can only grow under certain conditions—a plentiful supply of water to its roots and air to its leaves—and it must also have free access to sunlight. In the failure of such conditions the plant does not grow.

Its foodstuff is necessarily contained in the air surrounding its green leaves and in the water of the soil that contains its roots. Examining the air contained in an enclosed space, we find that

* Insectivorous plants.

this consists of about 79 per cent. of nitrogen, 21 per cent. of oxygen, and a trace of carbonic acid. If we next examine the air of an isolated space which has been used by plants, we shall find that its percentage of carbonic acid has been greatly diminished, while that of oxygen has increased. Evidently the effect of plant life is to rob the atmosphere of its carbonic acid and to enrich it with oxygen—just the opposite to that of animal life. If, further, we proceed to examine the water which is taken up by the roots, we shall find that this is not pure, but always contains mineral substances like nitrates, chlorides of potash and magnesium, salts of iron and lime, phosphates, silica, sulphates, etc., and it can be proved that the effect of plant metabolism is to take such substances from the soil water.

The materials from which the green plant builds up its tissues are therefore water, carbonic acid, nitrates, and other simple mineral substances. These materials it converts into proteids, oils, and waxes, and carbohydrates such as starch, sugar, and cellulose. Now all of the latter substances contain much potential energy, for, if we dry them, we can burn them and so obtain heat. But the water, carbonic acid, and mineral salts cannot be oxidised further, and they contain no available energy. In building up its tissues the green plant must therefore obtain energy from somewhere, and it can be proved that it is obtained from light; if the plant is kept in the dark, there can be no growth.* But it can grow in the light radiated from an electric arc It is, in fact, fairly easy to show that a green leaf exposed to sunlight is continually forming starch, while, if it is kept in the dark, no such thing happens.

Here, then, we have the source of energy of the green leaf. Outside the latter is water (OH_2), carbonic acid (CO_2), and solar radiation; and inside it is the mixture of pigments called chlorophyll. The solar radiation is not heat, although it is transformed into heat when it impinges upon most material objects. When it falls upon certain substances, such as luminous paints, it is transformed into light, and in certain conditions it can be transformed directly into mechanical work. When it impinges on the green leaf and is absorbed by the chlorophyll pigments, it is immediately transformed into chemical energy; for it can be proved that there is no starch in a leaf which is kept

* No increase in mass, although a seed—a potato, for instance—may *germinate* in the dark.

in the dark for some time, while within a few minutes of its exposure to sunlight starch accumulates in the cells.

It is difficult to convince the non-chemical reader what a very extraordinary thing this process of photo-synthesis of starch by the green plants must be. Let him note that on the one hand there is water and carbonic acid, and on the other there is dextrose and finally starch. The chemical equation is (probably):

$$\underset{\text{Carbonic acid}}{6CO_2} + \underset{\text{Water}}{6H_2O} = \underset{\text{Dextrose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}.$$

Then the dextrose is converted into starch $(C_6H_{10}O_5)n$, and the latter gathers in the cells of the leaf till it is required by the plant, when it passes into solution as dextrose, and is removed from the leaf by the circulating sap juices. This is the process of photo-synthesis. Look, however, at the first equation and read it from right to left. There is dextrose and oxygen. Dextrose is a highly combustible substance, and when it burns it combines with oxygen to form CO_2 and OH_2, with the liberation of a large quantity of energy in the form of heat. What actually occurs in the plant, however, is represented by reading the equation from left to right, and this shows that when the CO_2 and OH_2 are synthesised in the plant to form dextrose, the same quantity of energy must be absorbed as is liberated when dextrose burns in oxygen to form CO_2 and OH_2.

The former kind of reaction—an endothermic one—can *be made to* occur. A chemist can decompose CO_2 into C and O, as, for instance, when a burning piece of magnesium ribbon is placed in a jar containing CO_2. But the CO_2 is only decomposed into carbon and oxygen if a large quantity of energy is supplied in the form of the heat liberated by the burning magnesium, and so the decomposition only occurs at a relatively high temperature. The following statement is very important in all such discussions as these: reactions like that in which CO_2 is decomposed into C and O_2 only occur when a compensatory energy transformation is brought about—that is, when at least as much energy is supplied from outside as would be yielded if the reaction went in the opposite direction. Such reactions—an endothermic process coupled with a compensatory one—do not occur of themselves. When they do occur, the coupling is the consequence of some outside agency.

In the green plant, however, it is precisely this coupled reaction

that occurs. CO_2 and H_2O are combined together, and the energy necessary to bring about the combination is taken from the sunlight. A chemist could cause the combination to take place at a very high temperature and in quite special conditions, but it occurs in the green plant of itself, and at ordinary temperatures.

All the above is very important, and may not be neglected when we are considering the nature of the living process. We return to the matter in a later chapter.

The Balance of Life.—We see now in what way the energy degraded by animal life becomes rebuilt up again. The animal takes proteids, fats, and carbohydrates into its body, disintegrates and oxidises these compounds, makes use of their contained energy to obtain heat and do mechanical work, and then excretes the products of disintegration and oxidation in the form of water, carbonic acid, and urea.

The bacteria convert the urea (and other nitrogenous residues) into nitrate.

The green plants take energy from solar radiation, and rebuild water, carbonic acid, and nitrate into proteid, fat, and carbohydrate, when the cycle of operations recommences.

Now it is easy to see that all animal life depends upon plant life. Animals are carnivorous (feeding upon flesh), or herbivorous (feeding upon vegetable substances), or omnivorous (eating both flesh and vegetable substance). There are also some animals which are called *saprozoic*, with regard to their manner of nutrition, and these can utilise as food liquids or débris containing broken-down organic matter. Here we need not consider the saprozoic organisms, and it is enough for our present purpose to regard animals as either carnivorous or herbivorous, or both. Since the carnivores eat other carnivores or herbivores, or both, and since the herbivores eat vegetable tissues, it is easy to see that all animal life on the earth ultimately depends upon vegetable life.

On the other hand, vegetable life depends for its continuance on a supply of water, carbonic acid, and nitrate. The quantity of water on the earth is (for our purpose) unlimited, but not so the quantity of carbonic acid and nitrate, and upon the supplies of the latter substances the abundance of vegetable life hangs. What, then, are the sources of carbonic acid and nitrate? Some quantity of each substance comes from the earth in the exhalations from volcanoes, and possibly as the results of the disintegration of certain mineral substances. There is probably far more

CO_2 in the atmosphere and dissolved in fresh and sea water than the plants are able to utilise—that is to say, there is a surplus of both water and carbonic acid on the earth.

But this is not the case with nitrates and other inorganic nitrogen compounds, which are quite indispensable for the nutrition of plant life. There is an enormous quantity of elementary nitrogen in the atmosphere, but this is unavailable, for, in order to utilise it, plants must have it in combination with oxygen (as nitrous and nitric acids), or with hydrogen (as ammonia). Some nitrogen is always being combined with oxygen as the result of electric discharges in the atmosphere, and even under the influence of solar radiation; but, on the other hand, some nitrate, nitrite, and ammonia are always being decomposed into elementary nitrogen by certain bacteria present in water and soil. Therefore the total amount of nitrogen in the forms of nitrate, nitrite, and ammonia, and thus available for the nutrition of plants, is nearly constant, and certainly does not change appreciably during very long periods of time. That means that the total average quantity of vegetable life on the earth is practically the same from year to year.

And that being so, the total average quantity of animal life on the earth is also practically the same from year to year over a great lapse of time, for all animal life depends for its continuance on vegetable life. There is a certain balance between the two kingdoms of life. In restricted areas of land and sea, and for restricted periods of time, either the plants or animals may predominate; but in the long-run there is a relation between the two masses of animal and plant substance, and this relation is a nearly constant one. If animal life becomes temporarily very abundant, vegetable life must decrease, because it is being used up to a greater extent than is normal, and this condition will in turn lead to a diminution of animal life.

Production and Consumption.—The reader will now see what is meant by "vital production." All animals eat organised substance—fats, proteids, and carbohydrates contained in the tissues of other animals and plants. They reduce these substances to the forms of water, carbonic acid, and certain nitrogenous residues, utilising the contained available energy for the production of mechanical work and heat. Then the working substance is thrown out of circulation and is no longer available for the sustenance of the animal organism. The latter is a consumer.

All the time solar energy is, so to speak, running to waste.

Falling upon the sea, it evaporates water, which rises up into the air as vapour, falls down as rain and snow, and returns to the sea in rivers, having done nothing of itself but wear away the land and generate heat by friction. The heat is radiated away into space, and is for ever lost to the earth. Falling upon rocks, stones, gravel, sand, soil, etc., and upon the atmosphere, the solar energy heats up all these substances to a slight degree; but again this heat is radiated away, and is therefore irretrievably lost. Apart from vegetable life, there is therefore a continual dissipation of solar energy.

But the green plants intervene. They absorb the solar radiation, utilising this to recombine the water, carbonic acid, and nitrate which result from animal metabolism. Apart from the activity of the plants, this energy would be dissipated and the products of animal life would remain unavailable for further life. They are, however, recombined by the plants, and the solar energy which would otherwise be wasted is thus fixed. The plants are producers.

In the past plant life has, on the whole, been more active than animal life, and the result is the accumulations of coal (and perhaps oil) upon which modern industrial civilisation is based. This civilisation we must, however, regard as merely an episode in the history of terrestrial life, for the enormous increase of human population during the last few centuries has only been possible by the utilisation of the materials produced by a former surplus of vegetable life. With the depletion of this surplus the balance will be restored. It would, of course, be very rash to regard the future reduction of the human population of the earth as inevitable, for there may be other immense accumulations of energy in that now bound in the atoms of some material substances. Also some supply of energy may be obtained from the tides, winds, and rivers. But, again, it would be very foolish to count upon this possibility, for all that we know so far about radio-active transformations suggests that the process is one which we cannot initiate or control, and that the energy of the atoms, all but a very insignificant fraction, is bound. Also, the practical difficulties in the way of utilising tidal energy are probably enormous. Now coal and oil are diminishing rather rapidly, and there are no other sources of energy so far available. Therefore it seems safe to assume a return to an agricultural and pastoral civilisation, and with that a great reduction of population.

CHAPTER VI

BRAIN AND NERVE

THE next thing we must consider is the means whereby the various activities of the animal body are linked together and co-ordinated. What has already been said indicated the existence of such co-ordinations, but it will be useful to give an illustration.

A man, then, engages in sudden vigorous exercise. First of all he flushes and feels warm (though the temperature of his body does not increase appreciably). He breathes more deeply and rapidly than is normally the case. His respiratory movements also deepen and quicken. The rate of the heart-beat is increased. The skin becomes moist.

Apart altogether from the series of nervous impulses that issue from the spinal cord and brain to actuate the muscles that are in movement, and apart also from the series of impulses that stream into the central nervous system from the muscles and skin, there are other mechanisms in operation. These effect regulations of functioning. First of all the mechanical work done by the contracting muscles leads to a production of heat and carbonic acid, both being due to the oxidation of chemical substances contained in the muscle fibres. The carbonic acid is absorbed by the blood-stream, so that the percentage of this substance in solution tends to rise. Now there is a little group of nerve cells (the respiratory centre or "vital knot") in the medulla, and this is susceptible to changes in the quantity of oxygen and carbonic acid carried in the blood that traverses it. When this percentage of CO_2 is greater than normal, the automatic activity of the centre is accelerated, and *vice versa*. Rhythmic impulses issue from it at an average rate, and actuate the muscles of the chest wall and diaphragm. Therefore, when the quantity of CO_2 in the blood increases as the result of increased muscular activity, the respiratory movements are automatically accelerated; there is a greater ventilation of the lung cavities, more oxygen is absorbed and more CO_2 is excreted, and the composition of the blood tends to go back to that which is normal.

The heart-beat is a rhythmic automatic one, and it occurs at

a certain average rate. But the organ is controlled by two sets of nerves, some of which issue from the medulla *via* the tenth (or vagus) cranial nerve, and are acceleratory ones, while others come from the cervical sympathetic ganglia and are inhibitory in their function (see p. 141). Increase of CO_2 in the blood-stream affects the nerve cells from which these fibres originate in opposite ways; it tends to quicken the rate of impulses descending the sympathetic nerves, and so the heart's beat becomes accelerated or quickened. More blood traverses the contracting muscles, carrying nutritive matter and oxygen, and taking away carbonic acid; and at the same time more blood flows through the capillaries in the lungs, so that more oxygen than usual is taken up from the air in the lungs and more carbonic acid gas is excreted.

There are other nervous centres which control the calibre of the small arteries carrying blood to the skin. The walls of these vessels contain muscle fibres which diminish the calibres of the arteries, whereupon the latter contract, or they increase it, and then the vessels relax. Two sets of nerve fibres, derived from the sympathetic nervous system, go to the muscles of the cutaneous bloodvessels, one set, which is called vaso-constrictor (constricting the arteries), and another set called vaso-dilator (dilating them). The effect of the sudden generation of heat and carbonic acid is to set up reactions in the central nervous system which lead to the issue of nervous impulses, *via* the sympathetic ganglia, to the cutaneous bloodvessels, causing the latter to dilate. More blood then passes through the skin than usual, the latter flushes, and the sweat glands become more active than is normally the case. The skin becomes moist, there is evaporation of water from its surface, and so the heat generated by the muscular activity is eliminated.

Here we have a series of regulations carried out by the nervous system. One set of organs, the muscles of the trunk and limbs, have been functioning at a greater rate than usual, and the effect of this alone would be to disturb the general balance of bodily activity. Heart, respiratory organs, and skin are therefore stimulated by the central nervous system also to function more vigorously than usual, so that the increased activity of the muscular organs is compensated.

The nervous system is therefore the mechanism of regulation, co-ordination, and integration of bodily activities, and it is from this point of view that we study it. But first of all we must

consider it as a structure—an assemblage of nerve cells and nerve fibres arranged in a most complex manner.

The General Scheme.—The *central nervous system* of a vertebrate animal consists of masses of nerve cells called *ganglia*, and these are aggregated together as the *brain*, the *spinal cord*, and the *sympathetic ganglia*. They are connected together by *commissural* (or connecting) strands of nerve fibres, and they are also connected with the sense organs, muscles, and other parts of the body by nerves. The latter are bundles of nerve fibres varying in diameter from about $\frac{1}{4}$ inch (the great sciatic nerve of the leg), down to fine threads which are just visible to the naked eye. The nerve fibres themselves are just beyond the limits of unaided vision. A nerve issuing from the brain or spinal cord, or from a sympathetic ganglion, breaks up into finer branches, and these branches divide again and again until the whole is decomposed into its constituent fibres. The latter end in muscle fibres or among the cells of a gland or some other organ. In a sense organ, such as the eye or ear, there are great numbers of nerve cells, from each of which a single nerve fibre starts. These individual fibres become united into a nerve, and the latter (as in the case of the optic or auditory nerves) may go directly to the brain, or they may join with the bundles of fibres coming from other sense organs, and so reach the brain or spinal cord.

Thus we have two main divisions of the nervous system: (1) The central parts, consisting of the ganglia with their connections; and (2) the peripheral parts, consisting of the nerves going from the organs of sense into the brain and spinal cord, and of the nerves going out from the brain to the muscles, glands, and viscera. The peripheral nerves, whether outgoing or ingoing, are distributed to every part of the body, forming a network of fibres which is everywhere a very fine one, but which becomes finer and finer the more important is the organ to which they are distributed.

Now a very diagrammatic and undetailed picture of the nervous system would show the following parts (Fig. 21):

We see that the whole consists of the brain, which is divided into several principal parts: the *cerebrum* or great brain, the *cerebellum* or little brain, and the *medulla*. The spinal cord is to be regarded as the prolongation backward of the medulla. From the brain there issue out ten pairs of *cranial nerves*, which consist of fibres either going to or coming from the parts of the head, face, and neck (with a few organs in the body cavities). From

the spinal cord there issue out *spinal nerves,* one pair at each joint of the vertebral column. These also consist of fibres going to and coming from the body, limbs, and skin. Along either side of the vertebral column are other two series of outlying nerve ganglia which form the *sympathetic nervous system,* and these

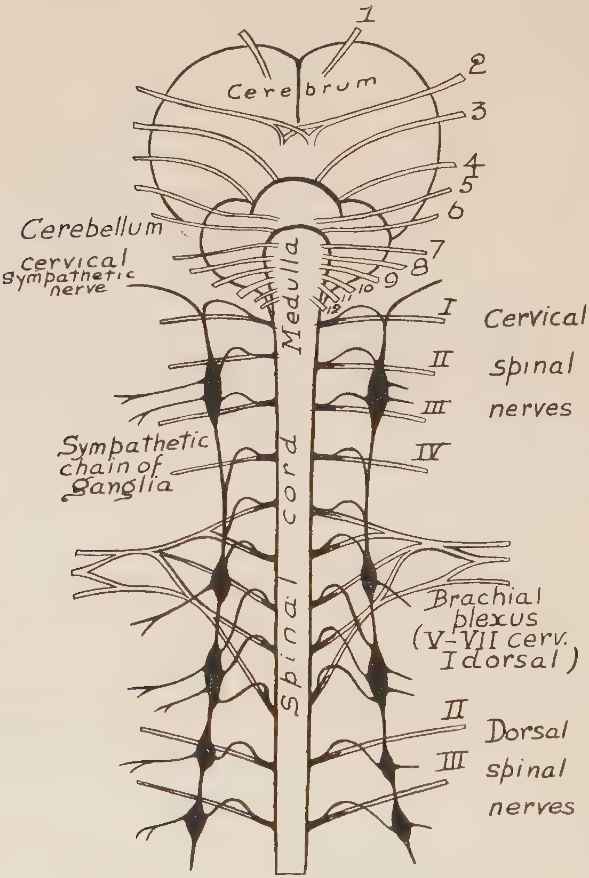

Fig. 21.—A General Diagram of the Central Parts of the Human Nervous System.

The sympathetic ganglia and their main connections with the spinal nerves are represented in black.

ganglia are all connected with the spinal nerves by communicating branches. Most people are familiar with the "solar plexus," which is an important part of the sympathetic nervous system. The cranial nerves go mainly to the muscles of the face and eyes, or come from the great sense organs of the head. The

spinal nerves go mainly to the muscles of the trunk and limbs, or come from sense organs in the muscles, joints, tendons, and skin. The nerves which go out from the sympathetic ganglia are connected mainly with the bloodvessels and viscera.

Examining these structures with the aid of the microscope, we find two main kinds of tissue. The central part of the spinal cord, the superficial part of the cerebrum and cerebellum, much of the deeper part of the brain and the sympathetic ganglia are all called "grey matter," and here the substance of the central nervous system is made of up nerve cells with their dendrites. The superficial parts of the spinal cord, the deeper parts of the cerebrum and cerebellum, and much of the other parts of the brain are composed of "white matter," and this consists of nerve fibres possessing a medullary sheath. The nerves issuing

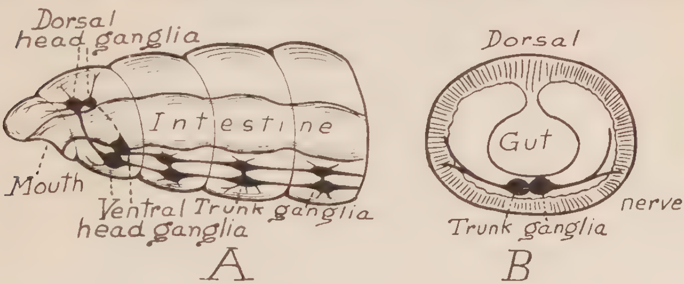

FIG. 22.—THE NERVOUS SYSTEM OF THE EARTHWORM.
A, The head parts; *B*, a section through the body.

from the brain and spinal cord are also composed of white matter, but those coming from the sympathetic ganglia are rather different in appearance, since they do not possess medullary sheaths. Two kinds of tissue—nerve cells and nerve fibres—therefore make up the nervous system, central and peripheral.

The Arrangement of the Ganglia.—Consider first such a very simple nervous system as that of an earthworm. This animal possesses a segmented or jointed body, and every segment is, on the whole, similar to the one in front or behind it. In each segment there is a pair of nerve ganglia connected together across the middle line of the body by a commissure. The ganglia are also connected together, each with the one in front and that behind. In the first or "head" segment of the worm, the ganglia are bigger than those in the body segments, and they are arranged to form a nerve collar round the œsophagus. These

two pairs of head ganglia may be called the "brain" of the animal. Nerves issue from the ganglia and go to the muscles, skin, and other organs of the segment, and (in general) the organs in each segment are supplied with nerves that originate in the two ganglia belonging to that segment.

This is a very simple and easily understood scheme, and, strange as it may appear, it is essentially the same scheme as that of the nervous system of the higher animal, such as man. There also the body is built up of segments, and though the latter are not very evident in the adult stage, they can, easily enough, be made out in the embryonic condition. Each segment contains a pair of ganglia from which nerves go out to the organs of the body. But the foremost segments have become coalesced to form the head, and the ganglia have therefore fused together as the brain. Further, all the ganglia in the trunk region have been greatly enlarged, and so have coalesced to make the grey matter of the spinal cord. The white matter of the brain and spinal cord corresponds to the commissural nervous tracts (longitudinal and transverse) of the earthworm. There are very many complications, and it would be wrong to press the analogy too closely; still, it is a true one: the central nervous system of the higher animal consists of a series of ganglia grown together to form the brain and spinal cord. But although this grey matter is almost continuous, we can recognise the existence of a very complex system of "commissures" connecting together its centres, or the positions of the original ganglia.

We may next consider the arrangement of these nervous centres and commissural nervous tracts.

The Spinal Cord.—This is the thick strand of nervous tissue lying within the tunnel formed by the cavities within the joints of the vertebral column. It looks as if it were the drawn-out prolongation of the medullary part of the brain, but it is really to be regarded as that part of the central nervous system which is situated in the trunk, while the brain is the other part situated in the head. Looking at it in section (as if the spinal cord were cleanly cut across), we get the general arrangement suggested in the figure. The central part of the cord consists of grey matter—that is, of nerve cells with their dendrites. The peripheral part consists of nerve fibres running lengthways in the cord. These fibres connect together the ganglionic matter of the brain with that of the cord, and they also connect together

the different segments of the grey matter of the cord. Some of them are fibres of the spinal nerves that enter the cord.

Between every two adjacent vertebræ one spinal nerve goes out from the cord on each side. But each spinal nerve has two roots—dorsal (to the back) and ventral (towards the belly). The dorsal root consists of nerve fibres that carry impulses from the skin, muscles, tendons, joints, and viscera into the spinal cord, while the ventral root contains fibres that carry impulses out from the cord to the muscles and viscera. And, therefore, if the dorsal roots of several adjacent spinal nerves are severed, there is loss of sensation in some part of the trunk or limbs, for sensory impulses are thus prevented from entering the cord and passing up into the brain. And if several adjacent ventral roots

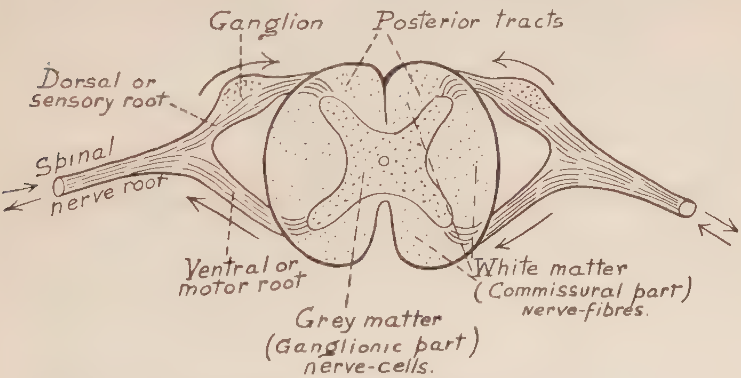

FIG. 23.—A DIAGRAMMATIC SECTION THROUGH THE SPINAL CORD, SHOWING THE ORIGIN OF THE SPINAL NERVES.

are severed, there is paralysis of the muscles in some part of the body. Several roots must be cut through to produce these effects, for, by a very beautiful arrangement, every part of the body receives nervous supply from several segments of the cord, and this overlapping of nervous and bodily segments minimises the effect of an accident. Allowing for the complications of the overlapping, we may say that each group of muscles in the trunk and each area of skin is under the control of one or more segments of the cord. The arms and legs, because of their great importance in locomotion and general acting, are supplied by a number of spinal nerves which unite together to form the limb " plexuses."

To a great extent the spinal cord is a path of conduction of nervous impulses from the brain to the body, and *vice versa*. But it is also a nervous controlling centre in itself, and when it is

cut off entirely from the brain it can regulate and co-ordinate bodily muscular actions and functions. A man, for instance, may "become a father" even when there is a lesion destroying the nervous connection between the brain and the centres in the cord which control the working of the genital organs—that is, those centres are autonomous. Generally speaking, the lower in the evolutionary scale an animal is the greater is the importance of the spinal cord relatively to the brain, and *vice versa*. It is functionally a series of semi-independent ganglia or centres of nervous control.

The Brain.—It is not certain how many segments have coalesced to form the head of a vertebrate animal. There are ten pairs of cranial nerves, and if we suppose that each of these is, in its origin, to be compared with a spinal nerve, there must be ten segments. But the whole question of head segments is very difficult. Certainly a number of the foremost ones form the head. Goethe thought he could recognise several modified vertebræ in the skull, and this was long afterwards the opinion of anatomists, but we now believe the Goethe-Oken homology to be incorrect. However, the concentration of the great organs of sense in the head and the variety and importance of the movements which are carried out by the eyes and jaws must have led to the concentration of central nervous mechanisms in the neighbourhood of these organs, and so established the lower brain centres.

For there are three central nervous systems in the brain—the "lower brain" (oldest), the cerebellum, and the cortex cerebri (the most recent). We must see how these have been evolved.

The Development of the Nervous System.—The *very first* thing to be formed in the embryonic development of a vertebrate animal is the central nervous system. A little groove, lying in the future axis of the body, forms in the embryo of a few days old, and then this closes up to form a tube. Soon the foremost (head) end of this tube swells out to form three vesicles, or bulb-like enlargements, and these are the "anlagen" of the brain. The rest of the structure of the animal becomes built up round the primary brain vesicles and spinal cord in a manner which is very difficult to explain, but exceedingly simple and "obvious" when one watches the developmental process in a vertebrate animal.

Very soon two little lateral vesicles are pushed out from the side walls of the fore-brain, and these become the cerebral hemispheres. The brain thus begins as a hollow organ, and the

cavities persist all through life as the ventricles, which are in open communication with the tubular cavity, or central canal, of the spinal cord.

Next the walls of the brain vesicles begin to thicken very unequally, and bending occurs. Thus, in the human embryo at about the middle of the eighth week we find the brain somewhat as given in Fig. 25.

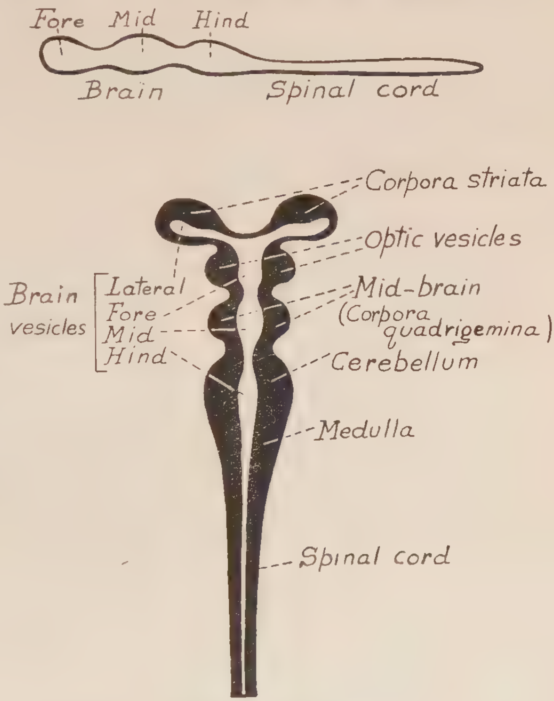

FIG. 24.—DEVELOPMENT OF THE BRAIN.

The upper figure shows the primitive brain tube and its vesicles. The lower figure shows further stages.

Fig. 25 represents the stage through which all vertebrate animals pass in the course of their embryogeny. The floor parts of the lateral vesicles thicken to form the *corpora striata;* the sides of the fore-vesicle similarly thicken, to become later on the *optic thalami* (or the parts in lower vertebrates corresponding to the human thalami); the roof of the mid-vesicle forms the *corpora quadrigemina* of man, or the lower vertebrate homologues of these ganglia; the roof of the front part of the hind-vesicle becomes the *cerebellum;* and the floor and sides of the posterior part become the *medulla.* The cerebellum is very small in fishes, and becomes more important as we rise in the scale, until it practically becomes a new part added to the primitive brain. The roofs of the lateral vesicles are never more than mere membranes, non-nervous structures, in fishes, but they thicken in

animals higher than fishes to become the cerebral hemispheres. The latter progressively increase in mass in the amphibia, reptiles, and birds, until they become the enormous lobes that we see in man, overarching and almost concealing all the other parts of the brain.

Thus we have the three developmental parts of the vertebrate brain:

The lower brain: corpora striata, optic thalami, mid-brain, incipient cerebellum, medulla;

The cerebellum;

The cerebral hemispheres with their **cortex.**

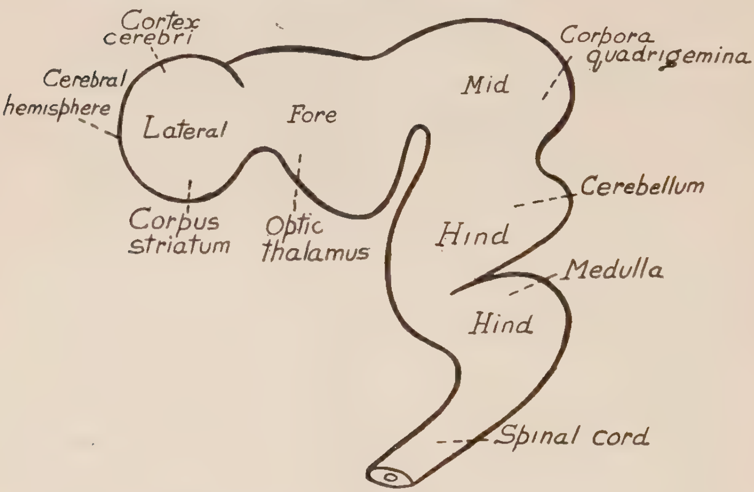

FIG. 25.—FURTHER STAGE IN THE DEVELOPMENT OF THE BRAIN.

The primitive lower brain in a fish, such as the cod, is very simple (Fig. 26). The mid-brain, with its great optic lobes, is the most important part. The fore-brain is the part lying between the two corpora striata. The cerebellum is not greatly developed. In its general characters such a brain as that which we have just described represents what we shall refer to hereafter as the "lower brain" of the higher mammal. Imagine the thin membranous "pallium" which covers the corpora striata to become enormously thickened and to grow backwards over all the rest of the brain, and suppose the cerebellum greatly to increase in mass relatively to the other parts. Then we should have the brain of the mammalian animal.

The Human Brain.—The human brain is represented in a very diagrammatic way in Fig. 27.

It is supposed that the whole organ has been cut through in a mid-vertical plane, and a number of details that are rather difficult to understand have been omitted from the diagram. The parts actually cut through are cross-hatched, and we see the central canal of the spinal cord widening out to form the "fourth ventricle" of the anatomists—that is, the primary hind-brain vesicle. Between this and the "third ventricle"—that is, the

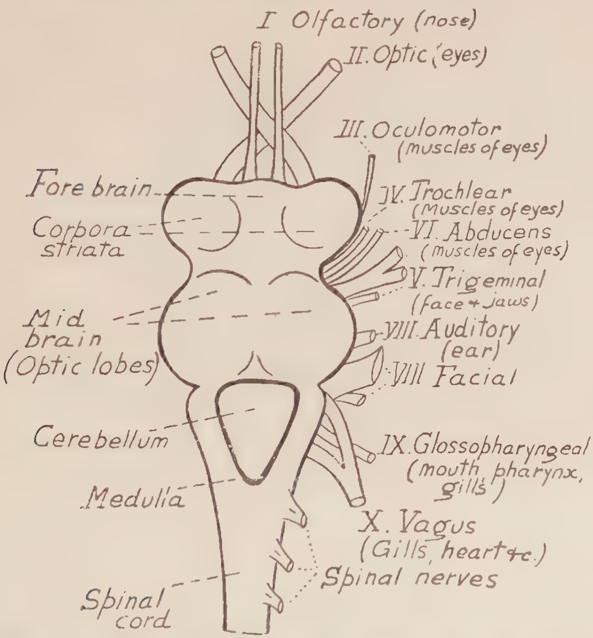

FIG. 26.—THE BRAIN OF A FISH (COD) SEEN FROM THE UPPER OR DORSAL SURFACE.

primary fore-brain vesicle—is a narrow passage which is the "aqueduct of Sylvius," and this represents the primary mid-brain vesicle. The floor, sides, and roof of the hind-brain vesicle are enormously thickened to form the cerebellum and the peduncles which connect it with the other parts of the brain. Similarly the roof, sides, and floor of the mid-brain vesicle have become thickened to form the corpora quadrigemina, and the great crura, or peduncles of the cerebrum, and some other parts. The roof and floor of the "third ventricle" remain thin, but the

lower parts of the sides are thickened to form the optic thalami, one of which is represented in the lateral wall in the figure. The enormous lobes, called the cerebral hemispheres, are the roofs of the primary lateral brain vesicles thickened to form the cerebral cortex with its systems of projection nerve fibres. In one corner of the third ventricle a little opening, called the *foramen of Monro*, is shown, and dotted lines indicate how this leads into a cavity in each cerebral hemisphere, called the "lateral ventricle." The cross-hatched part, called the *corpus callosum*, is the junction of

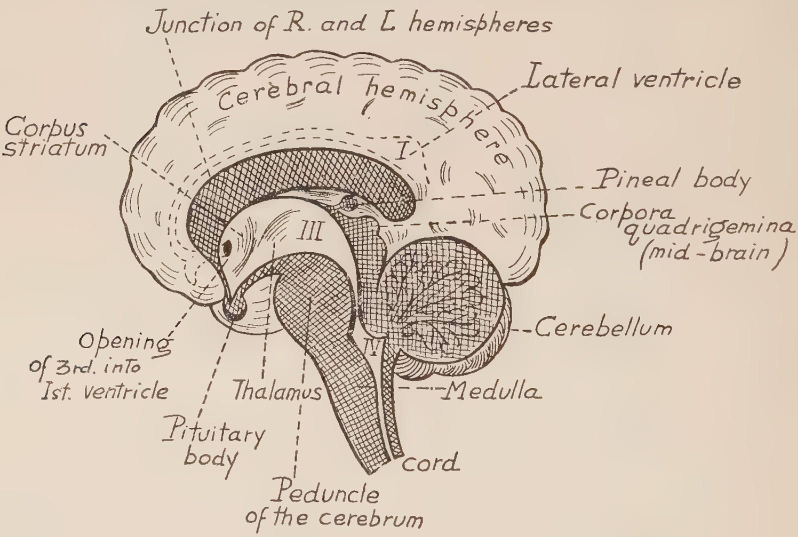

FIG. 27.—THE HUMAN BRAIN: AN IMAGINARY SECTION ALONG THE MIDDLE PLANE.

The cross-hatched areas represent the cut surfaces; the numbers I, III, and IV, show the lateral, third and fourth ventricles respectively.

the two (right and left) hemispheres. Just round the foramen of Monro the corpus striatum of the right-hand hemisphere is shown. This ganglion appears to bulge into the third ventricle, but it really belongs to the lower part of its cerebral hemisphere. Because of the enormous growth backwards of the latter organs, the relations of the various parts of the brain become difficult to visualise. Thus the corpus callosum appears to form the roof of the third ventricle, but this is not really the case. The roof consists of a delicate vascular membrane, which is not easily representable in a diagram, and the corpus collosum, with some other parts which are omitted, are the sections of the parts

of the two cerebral hemispheres which have coalesced by their internal faces.

The reader must not omit to note the two little bodies that are attached to the roof and floor of the third ventricle. That one attached to the roof is called the *pineal body*, and it was here that Descartes placed the seat of the soul. It is really a "vestigial organ" which has acquired a new function. Early in the history of the primitive vertebrates there were either one or more "cyclopean" eyes, and even in some of the lizards such eyes exist, though they are never functional organs of vision. In modern mammals the pineal body has become a ductless gland—that is, an organ that forms some substance which is discharged into the blood-stream. What the substance is we do not know, but it is said that it exercises an inhibitory influence, restraining precocity of growth and a too early maturity of the reproductive organs.

The organ on the floor of the third ventricle is called the *pituitary body*, and it also is a vestigial structure consisting of two parts, one of which appears to have formed the primitive vertebrate mouth. The pituitary body is a ductless gland secreting some substance into the blood which inhibits or controls the growth of the skeleton, particularly the bones of the face. Removal of the gland is always a fatal operation, and disease or hypertrophy produce curious exaggerations of growth, some of which, it has been noted, recall in bizarre fashion the characteristics of the extinct Neanderthal human race.

Connections within the Central Nervous System.

The white tracts in the spinal cord, in the peduncles of the cerebellum, and in the parts called the cerebral peduncles or crura in Fig. 27 are the great paths along which nervous impulses travel within the central nervous system. It is known that there are, in the white matter of the cord, two main categories of nerve fibres: (1) such as convey impulses to the brain—*ascending* tracts; and (2) those that transmit impulses from the brain to the grey matter of the cord—these are the *descending* tracts. Starting, then, with the white matter of the cord, we may next consider the main paths along which impulses travel in the central nervous system.

The Sensory Tracts.—First we take the ascending paths, those along which impulses originating as the results of stimulation of the receptor organs (see p. 106) reach the lower brain.

All sensory stimuli from the skin, the muscles, joints, and viscera pass into the spinal cord *via* the dorsal (or sensory) roots of the spinal nerves, and either go directly up to the brain or they enter the grey matter and undergo "relays"* there—that is, they are shunted on to new paths. Some of them pass out from the cord *via* relays and the motor roots, when reflex actions occur (see later), but the others travel up to the brain along tracts in the white matter. The great ascending tract in the cord is the bundle marked "posterior tracts" in Fig. 23, and this is made up mainly of nerve fibres which start from the cells in the grey matter round which the sensory root fibres terminate.

The upward path of these bundles is represented very diagrammatically in Fig. 28 as "great sensory tracts from cord to medulla." The individual fibres run up into the medulla, and end there as synapses round cells in two centres or nuclei, thus entering into a second relay. From these centres two new tracts, called the *lemnisci*, start. Immediately after leaving the nuclei the lemnisci cross or *decussate*—that is, the fibres starting from the right-hand nuclei cross over to the left-hand side, and *vice versa.* Running up through the crura of the lower brain, they end in the corpora quadrigemina and optic thalami, and this is their third relay. From these mid-brain nuclei new tracts of fibres start again, and proceed upwards into the cortex.

Thus the stimuli originating in the sense organs of the skin of the trunk and limbs, and in the muscles, joints, and viscera of those body regions, pass into the spinal cord, ascend the latter to end in the medullary ganglia. From there they travel to the mid-brain ganglia on the opposite sides of the brain, and from the mid-brain they proceed to the cerebral cortex. It is mostly the impulses giving rise to the sensations of touch, heat and cold, and pain originating by stimulation of the skin that take this very complicated path.

The impulses coming from the receptor organs in the muscles and joints mostly take a different path. They enter the grey matter of the cord *via* the sensory spinal nerve roots as before, and end in cells from which new ascending fibres start, or they may travel up in the white matter of the cord without first undergoing a relay in the grey matter. But in either case they take an independent course, and proceed to the cerebellum,

* A "relay" is an interruption in a nervous tract. One set of neurones join on to a new set by means of synapses.

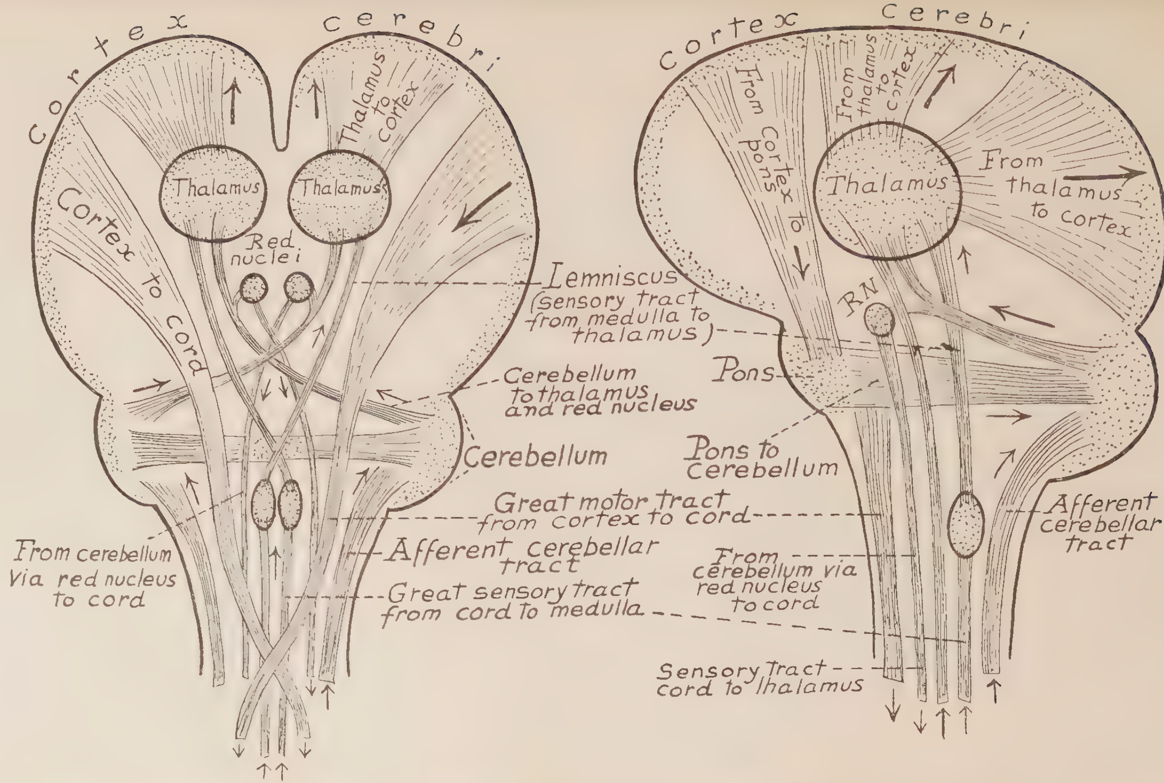

FIG. 28.—THE MAIN CONNECTIONS BETWEEN THE PRINCIPAL CENTRES IN THE BRAIN AND SPINAL CORD.

The left-hand figure represents the brain as seen from its base, while that on the right represents a side view. Both figures are purely diagrammatic.

entering the latter *via* the inferior peduncles. These are the tracts shown in Fig. 28, and called "afferent cerebellar tracts."

Thus the receptor organs in the trunk and limbs are connected with the ganglia contained in the mid-brain and cerebellum. This is also the case with the great receptors in the head—the visual, auditory, and gustatory organs; with the touch, heat, and cold receptors in the skin of head and face; and with the muscular and articular receptors in the same region, but not with the olfactory receptors. With the latter exception, all the nerve fibres starting from the sense organs in the head and face pass into the medulla *via* the cranial nerves, and end in separate nuclei. The latter are then connected in complex ways with the corpora quadrigemina, the optic thalami, and the cerebellum. The fibres carrying impulses from the olfactory organs are connected directly with the cerebrum; later on we shall consider the connections of the great sense organs in more detail.

Connections of the Cerebellum with the Other Parts of the Central Nervous System.—The cerebellum of a higher mammal is connected with the cord, mid-brain, and cortex by three great pairs of tracts contained in the cerebellar peduncles. The inferior peduncles are connected with the white and grey matter of the cord in the way just suggested, the superior peduncles are connected with the mid-brain (mainly corpora quadrigemina and thalami), and the opposite sides of the cerebellum are joined together by the middle peduncles which form what is called the *pons varolii*. Thus the cerebellum has a grip, so to speak, on the nuclei or ganglia which receive all the sensory impulses coming from every part of the body whatever. Further, since the grey matter of the cord and the nuclei of the cranial nerves are ganglia from which motor fibres go out to the muscles of body, limbs, and head, the cerebellum has also a grip on the centres controlling movements.

The Connections of the Cortex Cerebri with the Rest of the Central Nervous System.—The cerebral hemispheres are, we have seen, parts of the central nervous system which are superadded to the lower brain, inasmuch as each of them is to be regarded as a great lobe growing out on each side of the original fore-brain vesicle, expanding enormously, and arching over all the other parts of the brain. The base of each hemisphere is formed by the great ganglia called the corpora striata, and these come into close relationship with the ganglia of the fore-brain—

that is, the optic thalami. These two pairs of basal ganglia are present in the brains of all vertebrates, and we are regarding them here as parts of the "lower brain." The roofs and sides of the lateral fore-brain vesicles are either not present at all as nervous grey matter, or are imperfectly developed in the lower vertebrates, and they become very important only in the mammals. There they form a relatively thin sheet of grey matter which constitutes the superficial part of the hemispheres, and this increases so greatly in area that it becomes crumpled and folded in a complex way, so that it may be contained within the cranial cavity. The crumpling leads to the formation of the cerebral convolutions. There is therefore a thin layer of grey matter — the cortex cerebri—on the surface of each hemisphere, and beneath this there are great bundles of nerve fibres running in various ways. Beneath these bundles of white matter, again, are the basal ganglia.

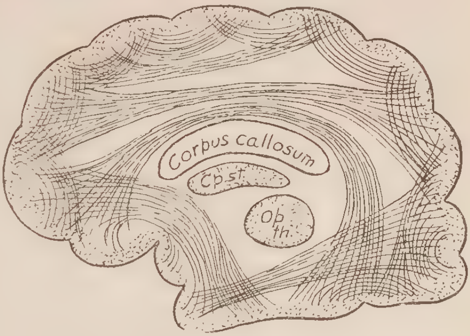

Fig. 29.—A Section through a Cerebral Hemisphere near the Middle Plane to show the Main Commisural Tracts.

The white matter of the cerebral hemispheres form two main categories of bundles—the commissural tracts and the projection tracts. We have dealt with the latter in Fig. 28. The commissural tracts are represented in Fig. 29.

One system of commissural tracts, represented chiefly by the corpus callosum, connect together the right and left halves of the cerebrum. Probably corresponding parts of the two hemispheres are joined by the fibres of the corpus callosum, but it is also possible that any one part of one hemisphere is connected with most parts of the other. In addition to these transverse commissural tracts there is an elaborate system of internal commissural or "association" tracts in each hemisphere, and some of these are represented in Fig. 29. They connect together the various convolutions, or groups of convolutions, by short paths, while longer tracts connect distant parts of the cortex with each other. More and more, as cerebral physiology de-

velops, do the interactions of one part of the cortex with other parts by means of the commissural and association tracts come to possess significance in the development of the manifestations of intelligence and higher mental faculties.

From all parts of the cortex bundles of fibres radiate inwards towards the cerebral peduncles; these form the "projection tracts"—those that connect the cortex with the lower brain and spinal cord. Some of the projection tracts are represented in Fig. 28 in a very schematic way. One, which is called the "great sensory tract," connects the parts of the cortex lying behind the Rolandic fissure (see Fig. 38) with the mid-brain ganglia; another tract of fibres, starting from the cortical region well in front of the Rolandic fissure, travels downwards and ends in the grey matter of the pons varolii, where it forms a series of relays with the fibres coming from the two sides of the cerebellum *via* the middle peduncles of the latter. This is the "tract from the cortex to the pons and cerebellum" of Fig. 28.

Thus the cortex is connected with the lower brain on the one hand by a direct tract, and with the cerebellum on the other hand by two indirect tracts, one *via* the mid-brain and the other *via* the pons and the middle peduncles.

The most important of all the projection tracts in man and the higher mammals is the *pyramidal tract*, that represented in Fig. 28, and called "the motor tract from the cortex to the cord." The fibres composing it start in the peculiar pyramidal cells of the cortical region lying in front of, and immediately round and in the depths of, the Rolandic fissure—that is, in the "motor area" of the cortex. These fibres are gathered up into two bundles which travel down in the crura of the brain towards the medulla, where they decussate, or cross, to the other side of the body. The crossing is not, however, complete, as the figure shows, and some of the pyramidal fibres remain on the same side of the body as that in which they originate. But most of them cross over. Running down in the white matter of the cord are therefore two descending tracts of fibres, "the direct and crossed pyramidal tracts." All these fibres pass into the grey matter of the cord, and end there as synapses round the cells that give off the fibres of the motor roots of the spinal nerves.

The pyramidal cortical tracts, with their nuclei in the cortex, are the typically "higher" parts of the mammalian brain. They are relatively small in such animals as the mole or the rabbit,

and more developed in the dog, and still more in the monkeys. In the anthropoid apes and in man they attain the maximal development, and are to be regarded as the paths along which those impulses travel that are the stimuli to what we call "willed" or spontaneous actions and movements.

This is a very summary account of the main features of the gross anatomy of the central nervous system, and we deal in greater detail later with the special nervous mechanisms. The reader should now be able to visualise the whole as a series of parts developing progressively in the course of the evolution of the vertebrate animals. Primarily there was a double series of ganglia, one pair in each segment of the body, and all of them were connected together by transverse and longitudinal commissural tracts. Nerves issuing from the ganglia were distributed to the sensory and motor organs of the body, conducting inwards impulses originating in the stimulation of the receptors, and conducting outwards impulses setting the muscles in movement or causing glands to function. With increasing complexity of bodily structure and greater freedom of movement the ganglia increased in mass and began to coalesce, thus forming the continuous core of grey matter of the cord, the hind, mid, and fore brain. The great sense organs became concentrated in the head, and so the cranial ganglia increased in functional importance, finally assuming the conditions that have been described.

There has been a progressive complexity in the movements included in locomotion as we ascend the series of evolutionary phases represented by the fishes, amphibia, reptiles, birds, and mammals. The need for precise adjustment and co-ordination of the impulses issuing from the spinal cord and setting muscular organs in motion therefore led to the development of specialised ganglia carrying out such functions, and so the cerebellum assumed the anatomical importance that it obviously has in the human brain.

And in the later stages of this evolution—that is, in the mammals—a kind of activity, connoted by the terms "intelligent," "spontaneous," and "volitional," became the characteristic one exhibited by these animals. This, we shall see, involved a nervous mechanism other than those of the midbrain and cerebellum, which are to be regarded as the ganglia controlling movements and activities that are largely "automatic." This mechanism, the latest one to be evolved, is contained in the cortex cerebri and its connections.

CHAPTER VII

THE SPECIAL NERVOUS MECHANISMS

The very general survey that we have just made of the rough anatomy of the central nervous system will enable the reader to study in greater detail the more special mechanisms into which we, rather arbitrarily, decompose the whole. These mechanisms are those of sensation, of motor control, and of co-ordination.

The Sensory Mechanisms.

"Sensation" involves the stimulation, by some physical agency, of receptor organs distributed everywhere in the body. We must suppose that all bodily tissues are irritable—that is, that they react in some way to stimuli, which may be chemical or physical. From what we know of the irritability of the surface tissues of the lower organisms, we may also conclude that this is a general irritability, and that the same tissue is potentially susceptible to light, electric, chemical, and mechanical stimuli. But in the higher animals the general irritability of the tissues of the lower organisms becomes modified by the evolution of the special organs of sense. We must think of this generalised susceptibility of the skin, say, as being restricted, so that any one kind of stimulus must be intense enough to pass over a "threshold"; if it is too feeble, the receptor is not stimulated at all. A special sense organ, therefore, is a part of the skin or other tissue where the height of the threshold is reduced for stimuli of some particular nature, and raised for all others. Thus the retina is a highly specialised part of the embryonic outer surface, which is extremely sensitive to the stimulus of light, but is relatively insusceptible to changes of atmospheric pressure, while its situation is such that it is not usually stimulated chemically, electrically, or mechanically. Similarly, the auditory hairs in the cochlear part of the internal ear are highly susceptible to sound vibrations occurring in the atmosphere outside, while they are so sequestered that they are not readily exposed to stimuli of any other kind. The nerve terminations of the olfactory and gustatory nerves in the mucous membranes of the nose and mouth are so placed that they are very readily

exposed to stimulation by chemical substances floating in the inspired air or dissolved in the liquids taken into the mouth, and they are highly sensitive to such chemical stimuli. On the other hand, they are not at all affected by light or sound vibrations, and mere physical contact with them of some solid insoluble substance only evokes a sensation of touch. All sensory surfaces are stimulated by electric discharges, as one may find by placing the electrodes from a battery cell on the tongue, but in such cases the sensation has not the quality of that which is evoked by the special agency appropriate to the sense organ.

A special sense organ consists, therefore, of the terminations (dendrites) of a nerve cell. The axon of this nerve cell forms one of the fibres in the sensory or afferent nerve which conveys into the central nervous system the impulses generated by the stimulation of the dendrites. As a rule the essential or special part of the sense organ is not so simple as we have indicated. Thus we have in the retina, or essential part of the organ of vision, the following structures at least:

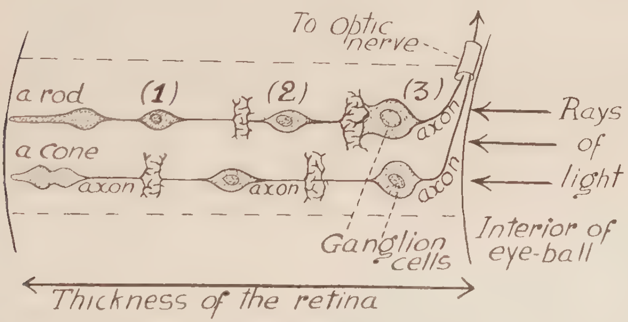

Fig. 30.—A Diagram of the Nervous Elements of the Retina.

The latter is supposed to be seen in section, the concave surface being that receiving the light from the pupil and the convex surface being that turned to the back of the eye.

The actual nerve terminations that receive the rays of light are the nerve cells, called the rods and cones (1). From these elements axons go off and make synapses with the dendrites of another nerve cell (2), which gives off an axon that enters into a synapse with a third nerve cell (3). The axon of this is prolonged out into the optic nerve, and so passes up into the brain. None of these nervous elements, or neurones, is in actual physical contact with another.

This is a very complicated instance, but it is the type of an essential sense receptor. There is always a terminal nerve cell, and the dendrites of this receive the physical stimulus and transmit it through synapses to other neurones, and, finally, *via* the sensory tract, to the cerebral centres. These terminal dendrites, or sensory nerve terminations, are peculiarly modified in each case, and their threshold is lowered, so that they are susceptible to one form of physical stimulus rather than others.

The non-nervous parts of the sense organ are concerned in transmitting the particular stimulus and in excluding others. Thus the retina is enclosed in the ball of the eye, and the front part of the latter (the cornea) is transparent, so that light can pass through it. Behind the cornea is the lens with the mechanisms for altering its focus, and the changing diaphragm, or iris, which regulates the amount of light that penetrates it. These *dioptric* parts of the eye are in every way comparable with a camera, lens, and diaphragm, which focus the external light upon a sensitive plate, making a picture there.

In the same way the ear consists of the outer, middle, and internal parts. Externally there is a stretched membrane (the drum), which is set in vibration by sound waves in the outer atmosphere. The drum communicates its motions to a chain of three small bones (the auditory ossicles), which again transmit the vibrations to the liquid contained in a cavity in the bone of the skull. This vibrating liquid then stimulates the nerve terminations of the cochlear (auditory) nerve in a most complex structure, called the organ of Corti, and the stimuli are transmitted along the cochlear nerve to the auditory centres. The organ of hearing thus excludes light, chemical and mechanical stimuli, but allows the periodic variations of atmospheric pressure that we call " sound " to reach the nerve terminations.

The nerve terminations in the mucous membranes of the mouth and nasal cavities are " bare "—that is, they are exposed to all physical stimuli: variations of temperature, some light, mechanical pressure, and chemical activity. But they are highly sensitive to the stimuli of different kinds of chemical substances, so that they can distinguish between the latter. And they are very susceptible in this way, so that, for instance, one easily tastes the difference between the flesh of, say, cod and haddock, or plaice and sole, a distinction which cannot yet be made by chemical analysis. The nerve terminations of the

olfactory nerve are still more delicate—even in man, in whom the sensation of smell is degenerate—and chemical substances existing in such small quantity in the air that they cannot be detected by any known methods of analysis are easily distinguished by smell. Still more incredible is the delicacy of the sense in such an animal as a bloodhound.

Heat receptors in the skin are nerve terminations that are stimulated by a rise of temperature above a certain limit, but are not affected by a fall below that. Cold receptors are, conversely, stimulated by a decrease, but not by an increase of temperature. Pressure receptors, or muscular sense receptors, are stimulated mechanically—that is, by something pressing on the skin, or by the degree of tension of a muscle, but not (or at least not much) by chemical changes in the skin or muscle, and not by changes of temperature. Equilibrium receptors, which are present in the "vestibular" part of the internal ear, are stimulated by changes in the position of the body with respect to its surroundings. Thus a man who is blindfolded has his ears and nose stopped, and who is lying immobile on a turn-table, can appreciate a noiseless, frictionless change in the position of his body, and can even roughly estimate the magnitude of the angle through which he is turned.

Thus the first step in the development of sensation consists in a refinement of the general irritability, or susceptibility to external changes, which we regard as one of the essential properties of living tissues. The "refinement" means that specialities of reaction are evolved: one kind of tissue, or arrangement of nerve terminations, becomes more sensitive to one kind of physical stimulus and less sensitive to all others. These specialised receptors then localise themselves in appropriate parts of the body, and become served by separate nerves. It is improbable that the fibres themselves are different in different sensory nerves—that is, could we transplant the auditory nerve fibres to the optic tracts, they would probably conduct optic stimuli just as well as they conducted auditory ones, and *vice versa*. The nerve fibres are conductors, and nothing more.

The next step is to place the fibres that transmit impulses from a receptor in connection with fibres that transmit impulses to a muscle or other effector organ, and that is done in the spinal cord, the lower brain, and the cerebellum. The sensory (or afferent) fibres enter into synapses with motor (or efferent)

fibres, and thus an impulse arising from the stimulus of some receptor owing to a change in the environment becomes converted into another kind of impulse that stimulates muscles to contract and relax, and so enables the animal to make an appropriate (or adaptive) response. But why "appropriate"? We discuss this question (but do not answer it) in a later chapter.

The lower brain, cerebellum, and spinal cord, are therefore centres (or ganglia) where afferent impulses become converted into efferent ones. They are simply the *loci* of synapses.

The last development of sensation is the becoming aware of the external changes that stimulate the receptors. It must not be thought that the development of consciousness of the environment, or of the body itself, is the sole, or even the main, function of the nervous system. What the latter does in the lower animals almost entirely, and what it mainly does, even in man, is to convert a sensory stimulus set up by some change in the environment into an appropriate response. Consciousness and psychical life doubtless accompany this conversion in all animals, though their intensity is the dimmer the lower in the scale of evolution the organism is placed. In ourselves this final development of sensation is the function of the cortex cerebri.

General Body Sensation.—Remembering, then, that the impulses arising from the stimulation of a receptor organ need not, and usually do not, give rise to changes of consciousness, we may consider, first, the paths by which the afferent impulses coming from the skin, muscles, and joints of the limbs and trunk reach the brain.

All such impulses enter the cord by the dorsal (or posterior) or sensory roots of the spinal nerves, but the paths along which they afterwards travel depend upon their nature. Those that arise as the stimulation of receptors in the deeper muscles and joints enter the grey matter of the cord, and are received by the synapses of nerve cells there. From these nerve cells axons pass out into the white matter, and these form nervous tracts on each side that go up through the medulla, enter the inferior peduncles of the cerebellum, and end in the grey matter of that part of the brain. At the same time other nerve fibres, carrying similar impulses, enter the cord by the sensory roots, and travel directly up in the white matter without first forming synapses in the grey matter.

Thus a large number of nerve fibres coming from the receptor organs in the deeper muscles and joints deliver their impulses into tracts of fibres in the cord, which then run up through the

medulla and the inferior peduncles of the cerebellum to end in the grey matter of the latter part of the brain.

But a large number of fibres entering the cord *via* the sensory roots take a very different course. These do not form synapses in the grey matter, but turn into the white matter at once, and form the two great tracts of fibres represented in Fig. 28 as the "great sensory tracts in the cord." These tracts end in the medulla in four prominent nuclei—that is to say, the fibres form synapses with the nerve cells in these ganglia. The axons passing out from the latter cells are collected together to form the two great sensory tracts called the lemnisci, and the latter, after crossing, as indicated in Fig. 28, run up into the corpora quadrigemina and optic thalami, and end by forming synapses with the cells in those nuclei. There they come into relation with nervous tracts passing out from the brain, and serving as the avenues along which motor impulses go out to the muscles of the body. So far, then, as we have studied it, the great sensory tract from the cord to the brain is one which carries impulses arising in the muscles and joints up into the mid-brain centres, *via* the ganglia in the medulla and the lemnisci tracts, and which, again, is mainly or solely a means of muscular co-ordination. In order that consciousness may be affected by these impulses, another link must be added to the chain of paths, and this is, we shall see, the tract of fibres passing up from the mid-brain to the cortex cerebri.

Lastly, impulses arising from the heat, cold, touch, and pain receptors in the skin pass into the cord through fibres in the sensory roots of the spinal nerves. These go into the grey matter directly, and form synapses round the nerve cells there. The axons of such cells go out again into the white matter of the cord, but they do not form a continuous tract of fibres. Instead of that, they run upwards only a short distance, turn back into the grey matter, form other synapses, and then re-enter the white matter to form another short tract. By a series of such linkages the impulses reach the medulla, and then pass up into the lower brain by a devious route. Finally, they become connected with tracts passing up into the cortex, when they undergo full development into psychical affections.

Thus the paths or tracts "mediating" general sensibility of the limbs and trunk lead up through the sensory roots of the spinal nerves and through the grey and white matter of the cord

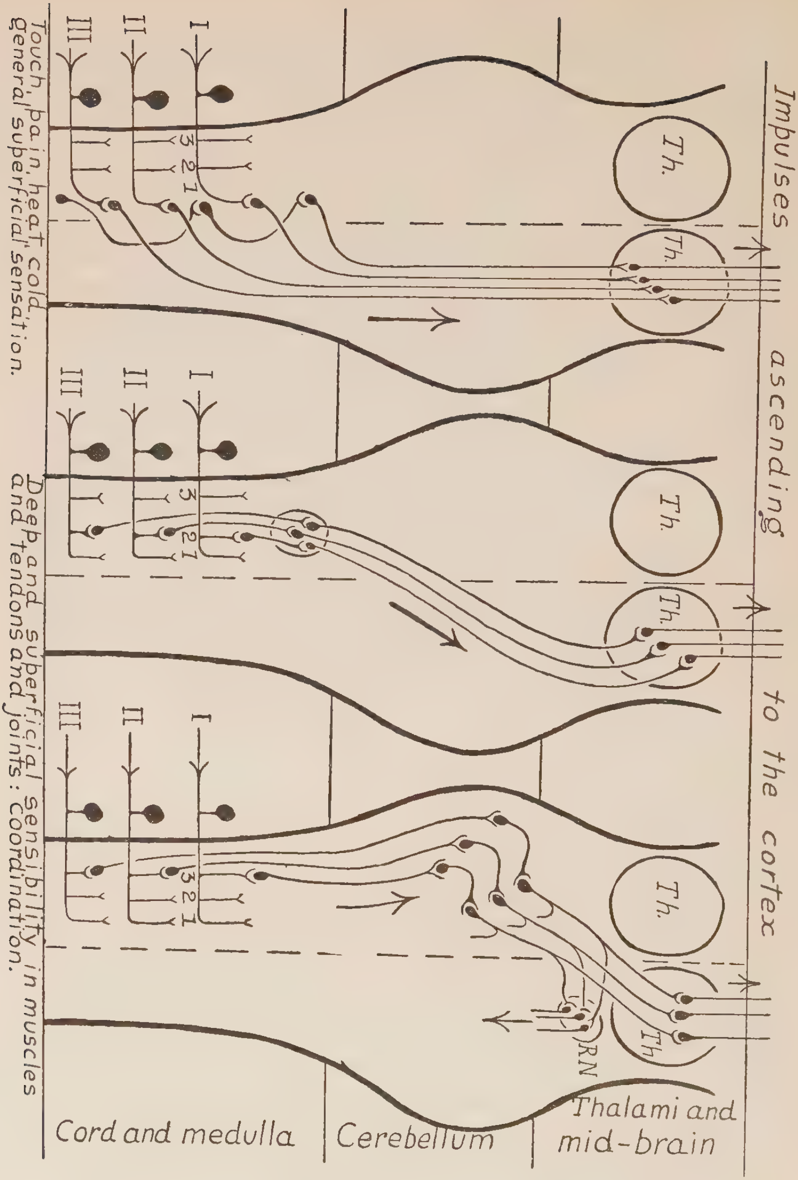

FIG. 31.—DIAGRAM OF THE MAIN PATHS OF NERVOUS IMPULSES FROM THE BODY INTO THE BRAIN.

Three spinal nerve fibres (I, II, III) are shown entering the cord. Each fibre divides into three branches.

Left: Impulses resulting from general sensation pass up in the cord as shown, entering into and again emerging from the grey matter; the connection is directly with the thalamus.

Centre: The paths taken by impulses coming from the muscles and joints; the connection is with the thalamus, but indirectly through nuclei in the medulla.

Right: The paths taken by impulses coming from the muscles and joints, and entering in the cerebellum, but also ascending to the cortex *via* the thalamus and returning to the cord *via* the red nucleus.

into the medulla. The greater number of the impulses passing along these paths are of the nature of stimuli, which lead to muscular responses only, and they are rearranged and co-ordinated in the cerebellum and mid-brain, so that the actions resulting from them are purposeful and appropriate. Some of them, but apparently only a small fraction of the total, proceed upwards to the cortex after passing through synapses in the medulla and mid-brain, and give rise to the changes of consciousness which we recognise as the sensations of pain, heat, cold, touch, pressure, resistance, etc.

General Sensibility in the Head.—The same kinds of general receptors are found in the skin, the muscles, and the joints in body, limbs, and head. But the impulses coming from the region of the head and face enter the central nervous system through the sensory fibres of the cranial nerves. Some of these are nerves of special sensation, and we consider them separately. Others (the 3rd, 4th, and 6th) are purely motor nerves, and go to the muscles of the eyes. The remainder (that is, the 5th, 7th, 9th, and 10th) are mixed—that is, they contain both sensory and motor fibres—and they may be compared with spinal nerves. They, with the purely motor nerves, convey efferent impulses from the medulla and mid-brain to the muscles of the eyes, face, jaws, and neck, and they also carry afferent impulses, arising as the result of the stimulation of the general receptors of those regions, into nuclei in the medulla and lower parts of the mid-brain. The internal paths in the brain are rather complicated, and we cannot attempt to describe them here; but there is the same general scheme as in the case of the special nerves: the afferent impulses coming from the face and head go up to the mid-brain, and through this to the cortex, on the one hand, and into the cerebellum on the other.

The Sensation of Smell.—This stands quite apart from all the other sensory mechanisms in that the connection of the olfactory organ is with the cortex direct, and not with the medulla and mid-brain. The organs of smell and vision and hearing have also a different embryogenic origin from that of the other sense organs in that they arise as parts of the brain, which become pushed out, so to speak, and come into relation with other parts arising from the embryonic integument. The auditory organs originate in this way from the hind-brain vesicle, the visual organs from the fore-brain vesicle, but the olfactory organs

arise as outgrowths from the lateral fore-brain vesicles that become, later on, the cerebral hemispheres. Therefore the connection of the nerve terminations in the mucous membranes of the nose are with the cortex cerebri direct, and this may be the reason why the sensation of smell is said to be more "reminiscent" than those of vision or hearing: it sets up more immediate "associations," because of its place of entrance into the higher brain. Less, however, is known about the internal tracts along which the olfactory impulses travel in man than in the lower animals, because of the degeneracy of the human organ of smell in comparison with that of most other vertebrate animals. In some fishes, for instance, the great development of the olfactory organs and their nervous tracts suggests that the sensation in question plays a very important part in the general behaviour of these animals.

The Auditory Organs.—Two entirely different sense organs are contained in the "internal ear." "Vibrations of sound"—that is, very rapid, periodically repeated alternations of compression and rarefaction of the air—are made to impinge on the tympanic membranes, or "drums of the ear," and then, by means of the chain of little bones, called the auditory ossicles, these vibratory movements of the drums are transmitted to the fluid contained in peculiarly shaped cavities in bones on each side of the head. Two organs are contained in this cavity, or "bony labyrinth"—the organ of equilibrium, and that of true hearing. The former consists of a little membranous sac from which proceed three semicircular canals, which are arranged in the three planes to which we refer all positions in abstract space. That is, one canal is vertical and runs forward and backward, another is vertical and runs from side to side at right angles to the first one, while the third is horizontal and is at right angles to the first and second. The dendrites of one branch of the eighth or auditory nerve project into the fluid contained in the bases of the semicircular canals. Operative interference in many animals and diseased conditions in man show that destruction of one or other of the canals produces well-marked abnormalities in locomotion, apparent giddiness, and lack of co-ordination over the muscles of the limbs. The "vestibular" part of the ear is therefore an organ of equilibrium, and its nerve terminates in a nucleus in the medulla, which is connected in ways that are not well known with the mid-brain on the one

hand, and the cerebellum on the other. There is, however, no evidence that it has any connections with the cortex.

The organ of hearing, called the "cochlea," is essentially a long tube bent on itself like a hairpin, and twisted round spirally like the shell of a periwinkle. Within this tube is a fluid which bathes a very peculiar and complicated structure called the organ of Corti. The fibres of the true auditory or cochlear nerve terminate in cells in the organ of Corti, and delicate auditory hairs project out from these cells into the fluid. When the latter is set in vibration, the auditory hairs are stimulated in such a way that afferent impulses are transmitted along the fibres of the nerve into two nuclei in the medulla, where they are received by synapses. The axons of the cells in these nuclei are now gathered up into certain internal tracts, which pass up along the lemnisci (see Fig. 28) into the mid-brain. Other fibres go to the cerebellum. From the cells in the mid-brain round which the axons of the lemnisci end other axons go up, along a very obvious tract, called the auditory radiations, into the sensory region of the cortex.

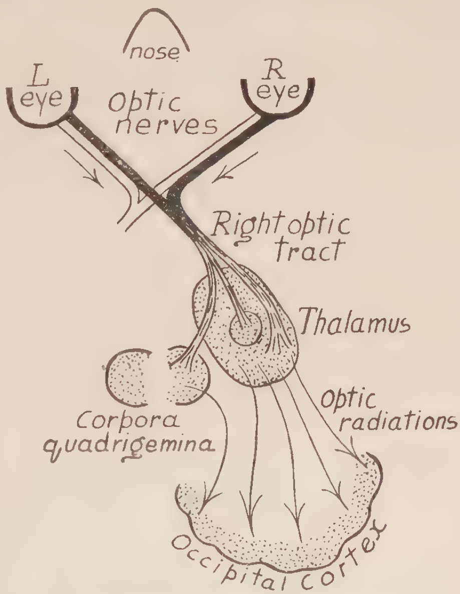

FIG. 32. THE CONNECTIONS OF THE RETINAS WITH THE BRAIN.

Only the tracts on one side are shown. The section of the brain represented diagrammatically passes rather obliquely through the eyes.

The Organs of Vision.—We have already said something about the general structure of the eyes. The essential elements are the cells of the retina, which, we have seen, are arranged in layers. Light is received by either the rods and cones, and these are prolonged into axons which form synapses with other "bipolar" cells, the axons of which form other synapses with third, "ganglionic" cells, the axons of which pass out of the retina into the optic nerve. The latter then run up towards the

mid-brain as the two optic tracts, which then partially cross each other in the middle line of the head. The further course of the optic tracts in the brain is now fairly well known.

Fig. 32 represents these tracts in a very schematic way. Some of the fibres of the right optic nerve pass over to the left-hand side of the brain, while some keep on the same side (and *vice versa*). Then all the optic fibres terminate by forming synapses with the cells in three nuclei contained in the optic thalami and corpora quadrigemina. That is their lower-brain termination, but a very obvious tract of other fibres, the optic radiations, start off as the axons of cells in the lower visual centres or nuclei, and proceed up to the cortex cerebri.

Audition and vision are complex sensations. When we hear we distinguish loudness (that is, the amplitude or "intensity" of the sound waves), pitch (which is the frequency of occurrence of the sound waves), and musical quality (which we explain by assuming that the sound waves are complex, and can be decomposed into components). Similarly, in vision we distinguish between intensity of light and quality of light (or colour). By intensity we mean the amplitude of the vibrations of the medium (ether) which transmits that which we recognise as light, and by colour we mean the components of this mixed light as they are separated from each other by the physical media outside the retina itself. How the analyses of sound and visual stimuli are carried out by the auditory and visual organs is, of course, far from being understood, and we cannot discuss the question now.

So much, then, for a very summary consideration of the ways by which the stimuli of the receptor organs of the body are transmitted into the central nervous system and brought to bear upon the various ganglia there. We must next consider—

The Motor Mechanisms.

From what has been said in Chapter II. the reader will already know that a motor mechanism includes (1) an afferent nervous path leading into the central nervous system; (2) a nucleus or ganglion; and (3) an efferent nervous path leading out from the ganglion to the motor organ. Thus we take the case of a purely special mechanism.

Some receptor organ is stimulated (say a touch spot in the skin), and an afferent impulse is set up and propagated along a spinal nerve into the grey matter of the cord. This impulse

enters the latter *via* the dorsal or sensory root. In the grey matter it is received by the dendrites of a nerve cell, and is then transferred (after something has been done with it) to the axon of the cell. This axon issues from the grey matter and passes out from the cord through the ventral or motor root of the same, or a different, spinal nerve, and is transmitted by the latter as an efferent impulse to a muscle which it then sets in motion.

This is merely a scheme illustrating the simplest conceivable form of nervous motor apparatus. It may be regarded as the unit

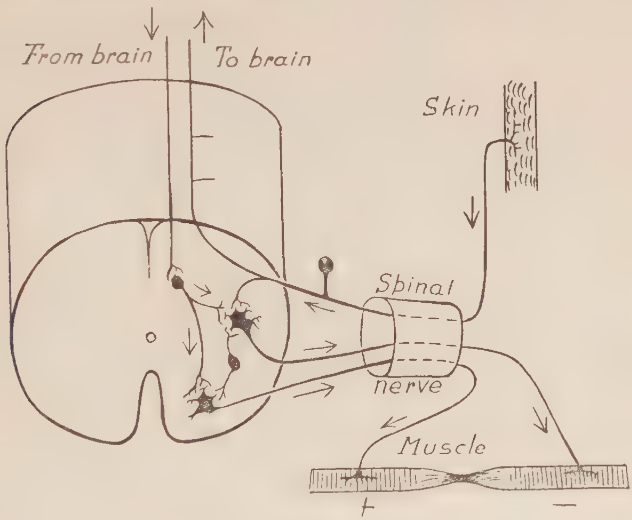

FIG. 33.—DIAGRAM OF THE SIMPLEST POSSIBLE SPINAL REFLEX MECHANISM.

An afferent fibre is represented as entering the cord, and ending in a synapse round a cell, which then sends out an axon to a muscle fibre. Through an additional cell and synapse another axon goes out to the antagonistic muscle. The + sign indicates that one muscle contracts, and the – sign that the antagonistic one relaxes.

or element of the sensori-motor mechanism, but the reader must be very clear in his mind that the very simplest actual nerve-muscle mechanism is very much more complicated than Fig. 33 suggests.

So we may now proceed to elaborate it till it approximates to the conditions that may be studied experimentally. First, then, one muscle never, by itself, constitutes a motor mechanism. For there are always two antagonistic organs, one of which contracts while the other simultaneously relaxes. Secondly, the nerve that supplies a muscle always contains fibres that carry

efferent or motor impulses from the nucleus (or ganglion) *to* the muscle, and also fibres that convey afferent or sensory impulses from the muscle to the nucleus. Thirdly, the stimulus that starts the nervous impulse and excites the muscular organs to activity nearly always originates in a different segment of the body from that containing the former, so that there must generally be a path, or tract, in the central nervous system itself along which the impulse travels. Lastly, there are hardly ever only two antagonistic muscles concerned in a movement, but rather a muscle system consisting of several or many such pairs. Thus the simplest actually observable action that can occur in the body of a higher animal includes a rather complicated mechanism, and the complexity of this becomes all the greater when we take account of the connections of the nucleus immediately controlling the action with the higher brain centres. When such connections exist we have the possibility that the action may be modifiable to almost any degree by the volition of the animal, or by its "experience."

Leaving aside, in the meantime, the factors of volition and experience, we may consider the action as it is performed in an automatic, mechanical manner. Let it be that which may occur when the side of the spinal dog* is tickled and the "scratching reflex" occurs (see pp. 119, 137).

Fig. 34 represents nervous mechanisms that are involved in this action. These mechanisms (to judge from the figure) appear to be somewhat complicated, and yet we have taken account only of those which must be in action, and we have omitted others that are less essential to our present explanation.

The stimulation, then, of the touch organs in the skin of the body sets up impulses that are transmitted to the spinal cord *via* the afferent fibres of a spinal nerve. Now this segment of the cord is well in front of that from which are given off the motor nerves supplying the hind-limb, and so there must be a nervous tract connecting centres (*a*) and (*b*). The afferent impulse, after being received by the synapses of the grey matter in centre (*a*), is modified in some way, is retransmitted along a tract of fibres in the white matter of the cord, and is received by motor nerve cells in segment (*b*). We must think about these motor nerve cells as being arranged in some way or other

* A "spinal animal" is one in which the brain has either been destroyed altogether (by operation) or has been separated from the spinal cord. Thus the muscles of the body are entirely controlled by the cord.

in pairs, some of them being the cells of axons that go to the flexor muscles, while others are the cells of axons that go to the extensors. Now the same impulse breaks upon both these series of axons, but it causes, at the same time, the flexor to contract and the (antagonistic) extensor to relax, thus bending the limb.

But the muscle fibres contain receptors which are stimulated by the acts of contraction and relaxation, and thus set up impulses that are propagated along the afferent nerve fibres coming from the muscle. These afferent fibres pass into the grey matter of the cord, and are received by nerve cells there. From the latter cells axons pass off and enter into synapses with the motor cells which control the movements of the muscles.

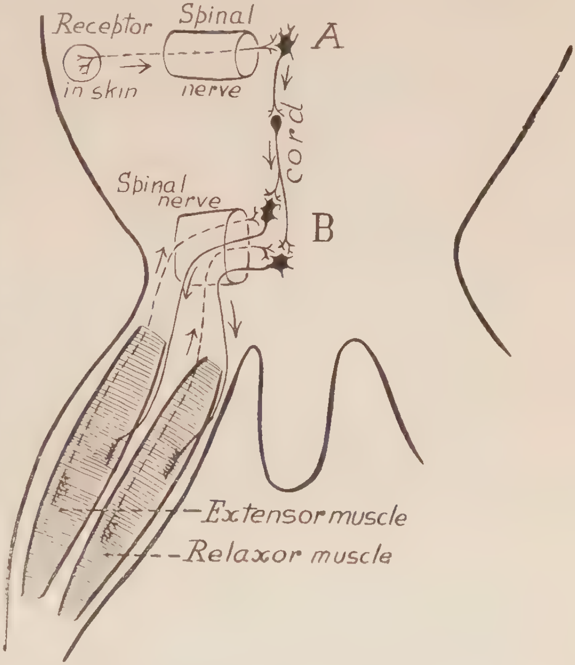

Fig. 34.—The Main Mechanisms involved in the Scratching Reflex of the Dog.

An afferent fibre enters the cord, and is connected by various cells, their synapses and axons with two motor cells in a lower segment. The latter send out axons to the two antagonistic muscles, and the muscles send up afferent fibres which come into connection, *via* synapses, with the motor cells.

Thus the muscular apparatus responds to a stimulus which enters the central nervous system at a place removed some distance from that place from which the motor nerves emerge, so that there are internal paths of communication in the cord. Also the contracting and relaxing muscles "advise" the motor centres (*via* their own receptors and afferent nerves) what they are doing, so to speak, so that the entire series of actions may be adjusted, or controlled, or accelerated, or inhibited, while they are still in progress.

Now add to all this (1) a new series of connections between the nerve cells of the grey matter in segment (*b*) and the cerebellum, and note that there must be two sets of paths, to and from the cerebellum, included in these connections. Add (2) a series of connections between the segment (*a*) and the mid-brain, also to and from paths; these are, of course, the tracts described on pp. 99–104 and in Figs. 28 and 31. Add, finally, (3), the connections between the mid-brain and the cortex on the one hand, and the mid-brain and the cerebellum on the other—these also being to and from paths—and the reader may get some idea of the complexity of the machinery of nerve cells and nerve tracts that are involved in a relatively simple action when it is the object of control by will or experience.

The "Simple" Reflex Mechanism.

The schematic simple reflex mechanism, such as it is figured in p. 117, is to be regarded as a "fiction" in the conventional, legal sense—that is to say, it is a "scheme" which is useful in enabling one to understand the maze of nervous tracts and paths along which impulses travel within the nervous system. If we could isolate all the afferent fibres connecting one group of nerve cells in the spinal cord with one group of receptor organs in the skin, these would represent the afferent path of a simple reflex. Then we should have to isolate all the nerve fibres connecting the same group of nerve cells with some one muscle, and that would be the efferent path. So we should obtain our schematic "reflex arc."

Nothing like this exists in the higher animal. The afferent impulses originating in any one small group of receptors do not go to one segment only in the spinal cord, but to several such. Each of these segments is connected with the same muscle, for the fibres going out from the cord through one motor root and ending in one muscle are derived from several segments. Thus one efferent and one peripheral afferent path are connected together by various nuclei, and these nuclei are joined by several intraspinal paths.

Then we have the further complications indicated in Fig. 34. The schematic single efferent paths are really double ones, each of them including a nerve branch going to a muscle and to its antagonist. The same impulse which breaks upon the synapse in the nucleus stimulates the nerve going to the muscle, so that

the latter contracts, and it also stimulates the nerve going to the antagonist, so that it relaxes. These two antagonistic effects must be regarded as the single functional muscular action—that is, their effect is, say, to bend or extend a limb.

But the movement of the limb is something that varies to a very great degree: the part may be completely or partially bent (or extended), and it may bend or extend against resistances which also vary immensely. The duration of the movement therefore varies, and so also does the quantity of energy transformed—more or less work is done according to the circumstances under which the action is performed. To some extent all this regulation is carried out in the nucleus from which the efferent impulses proceed out to the muscle, but it is also the work of the contracting (or relaxing) muscle itself. There are receptors in the latter which are affected or stimulated by the events taking place in it, and by the circumstances of the action—the load, for instance, borne by the contracting muscle. These receptors generate impulses which ascend into the nucleus and modify, if need be, the efferent impulses sent out by the latter.

A mechanical analogy may make this very important function of the muscle *proprioceptors* clear. Let us think about a small railway system in which the movements of every train are initiated and regulated by operators working in a central telegraphic control station. But as every train proceeds on its journey, moves from block to block, stops at and starts from a station, it records its position telegraphically (and perhaps automatically) on a time and space chart in the control office, so that the operator may see at each movement where it actually is. That would represent the system of efferent nerves going from the spinal cord nucleus to the muscular apparatus, and the receptors of the latter, with their afferent nerves, going back into the nucleus.

These, then, are the mechanisms concerned in the simplest spinal reflex arc: several cord segments in receipt of afferent impulses from the skin, and all of them in connection with the same small group of antagonistic muscles and a system of receptors in those muscles in connection with the nuclei from which the efferent impulses start.

The Cranio-Spinal Reflexes.

The muscular apparatus concerned in movements are, we have seen, under the immediate control of ganglia or nuclei in the spinal cord, or (what are very similar) the ganglia in the medulla

from which the motor fibres of the cranial nerves issue. Reflexes, or purposeful and useful adaptive movements, may be carried out under such control, and apart altogether from the activities of the brain, although there are probably very few actions into which some amount of brain control does not enter. So far we have supposed that the stimulus to an action is some change in the environment acting on receptor organs situated in the skin, but in the intact, normal animal it is far more likely that the

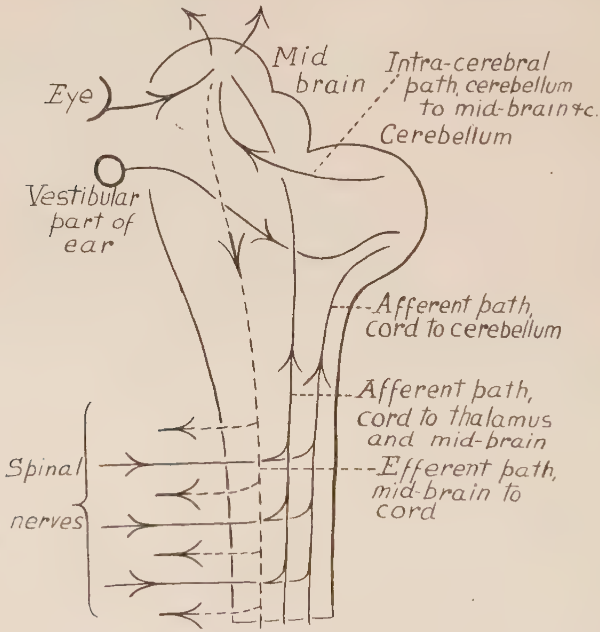

Fig. 35.—Afferent Impulses from the Skin are shown going up into the Thalamus, where Visual Impulses are also Received.

Other afferent impulses enter the cerebellum from the muscles. From the cerebellum impulses pass to the mid-brain, and from there motor impulses pass down through the cord, and to the muscles concerned in locomotion.

receptors stimulated will be one or several of the great cranial organs of special sense. Thus an animal usually responds to something which it sees, or hears, or smells, and so we must include among the afferent paths that take part in the reflexes, or other actions, those going from the visual, auditory, and olfactory organs into the mid-brain. Yet the impulses actually setting the muscles in action must issue from nuclei in the medulla and spinal cord, and must go out to the muscles *via* the motor

roots of the cranial and spinal nerves. That means, obviously, that there must be paths, confined to the central nervous system itself, along which impulses may travel from the nuclei of special sense in the mid-brain to the motor nuclei in the medulla and cord. The principal intracerebral and intraspinal paths, as well as those which pass from cord to brain, and *vice versa*, are represented in Fig. 28. Therefore our " simple " reflex, or other action, will (in the intact, normal animal) include all the paths, or analogous ones, represented in Fig. 33, and also another series of paths between the organs of special sense and the mid-brain, and between the latter and the medullary and spinal motor nuclei. Thus the main paths in use in the case of a man walking in a crowded street and " mechanically " avoiding other people must be somewhat as indicated in Fig. 35.

Here we do not represent the afferent paths between the acting muscles and the nuclei in the cord, and, of course, no details of the very imperfectly known paths between the mid-brain and spinal centres.

The Mechanism of Co-ordination.

Nor do we ever suggest the all-important apparatus of co-ordination. In such a complex series of actions as those involved in walking a very great number of muscular systems are at work. Practically all the muscles of the legs are active and immediately concerned in the production of the movements, but the body is also carried erect and balanced, and this is the work of antagonistic muscle systems belonging to the trunk. The arms swing about. At each step, and with every deviation from a straight line, the centre of gravity of the whole body changes its position. Practically every nucleus, or ganglion, in the whole spinal cord must be concerned in the generation of the impulses going out along the efferent nerves to the muscles, and in receiving the afferent impulses generated in the acting muscles and joints, and giving information from instant to instant as to what is going on there. Now it is unlikely that the relatively simple reflex mechanisms constituted by the sensory and other afferent nerves entering into synapses with the motor nerves is competent for this work of co-ordination, and there is much evidence that an additional nervous apparatus is involved.

This additional mechanism is the cerebellum and its connections. We have seen that there are tracts of nerve fibres passing

through the superior peduncles and putting the cerebellum in communication with the mid-brain, and so with the organs of special sense. The vestibular part of the auditory organ—that is, the part which is known experimentally to be concerned in the maintenance of equilibrium and posture of the body—has also direct nervous connection with the cerebellum. The receptors in the deeper muscles and joints are connected with the cerebellum by special tracts (see Fig. 31), and there are also descending tracts connecting this part of the brain with the motor nuclei of the spinal cord. Even the nuclei of the cranial nerves are connected with the cerebellum.

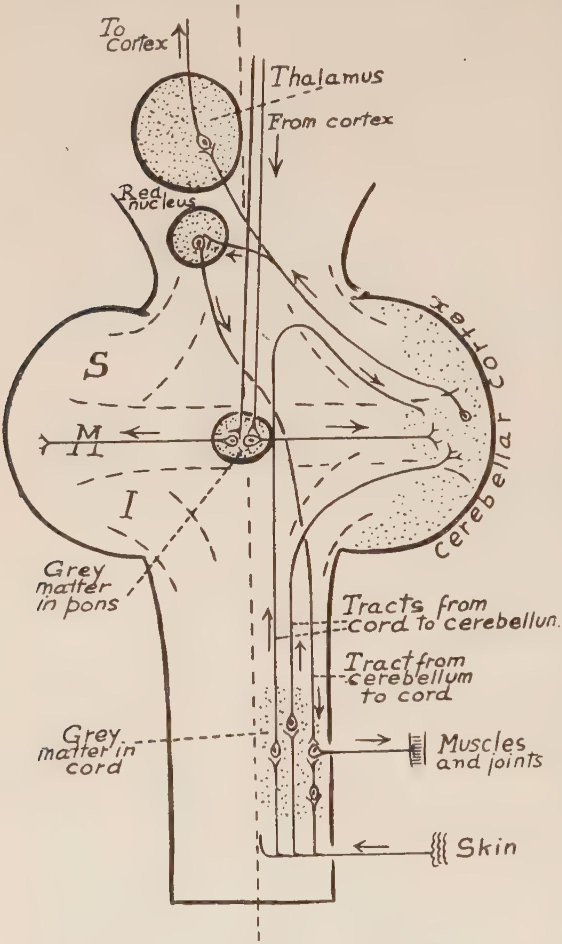

Fig. 36.—The Connections of the Cerebellum.
Impulses pass up from the skin, muscles, joints, etc., into the cerebellum, *via I*, the inferior, and *S*, the superior peduncles. From the cerebellum impulses pass to the thalami and red nuclei, and from the latter efferent impulses pass down into the cord. The cerebellum is also connected, *via M*, the middle peduncle, with the cortex, and in other ways, not shown in the diagram, with the organs of special sense.

It is known also, from direct experiments, that injuries to, or even removal of, the cerebellum leads to no obvious impairment of sensation, and yet the organ has most conspicuous

and direct connections with almost all kinds of receptors. But such injuries or operative interference do produce serious motor disturbances, so that ordinary, automatic, or customary movements, such as those of gait, locomotion, and posture, are greatly affected, and the animal when walking, running, swimming, or flying, behaves in an ineffective, incompetent manner. Whatever, then, are the functions of the cerebellum, it is very plain that they must be of considerable importance and are very complex—a deduction from the peculiar and most intricate structure of the grey matter of this organ. The general conclusion attained by the study of all these lines of evidence is that the work of co-ordination of movements performed customarily and automatically is carried out in the cerebellum. Impulses arising in the sense receptors are conveyed to their nuclei in the spinal cord and brain, or they may be conveyed directly into the cerebellum, and if the direct path does not exist, there is one connecting the immediate nucleus of the afferent impulses with the latter part of the brain. That is to say, the cerebellum is the recipient of impulses coming from the receptor organs, and particularly from those which have to do with equilibration and those others which come from the acting muscles themselves and from the joints (where the effort involved in the movements of the limbs must be particularly felt). On the other hand, the cerebellum also stands in close connection with the nuclei which give origin to impulses going out to the muscles of the limbs and body. There is, therefore, a mechanism whereby those complex movements which are the means of locomotion may be timed, adjusted, and co-ordinated, and this we suppose to be situated in the grey matter of the cerebellum. Of the nature of the mechanism we have not even a suggestion.

Cortical Control.

We shall consider in the next chapter the experimental evidence on which our knowledge of the functions of the cortex cerebri is based, and in the meantime we deal only with the nervous mechanisms themselves, so far as these have become known by anatomical research and experiment. The greater part of each cerebral hemisphere, then, is a core of nerve fibres making such connections as are indicated in Figs. 28 and 29—connections, that is, between the various parts of the cortex itself and between it and the other nuclei in the lower brain, cerebellum, and spinal cord. With the exception of the corpora

striata, the great nuclei of the cerebral hemispheres are situated in the thin sheet of cortical grey matter, and it is the cells of this that are connected with the underlying core of fibres. The latter are either the axons of these cells (in which case they carry impulses out from the cortex) or they end in forming synapses with the cortical cells (in which case they carry impulses to the cortex).

Fig. 37 represents, on the same scale, a "pyramidal" cortical cell from the frog's cortex and one from man; the actual cell bodies are very much the same in the two cases, but the dendrites and axons are very much more complex in the human than in

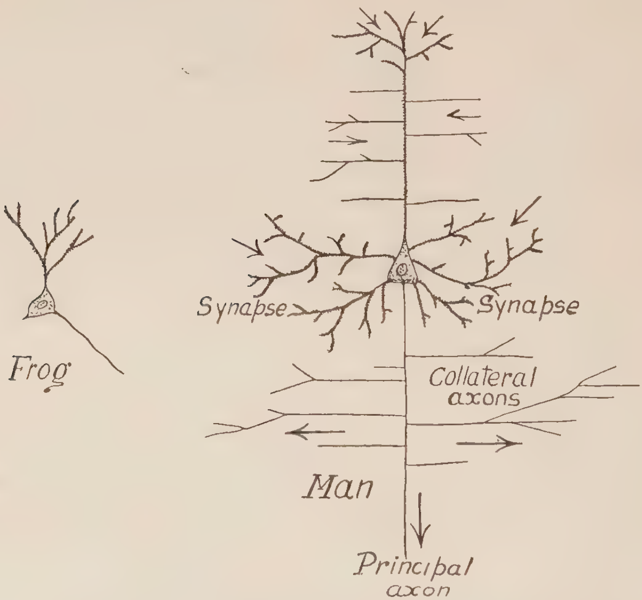

FIG. 37.—TWO CORTICAL (PYRAMIDAL) CELLS FROM THE BRAIN OF MAN AND THE FROG. HIGHLY MAGNIFIED.

the amphibian cortex. Each cell is pyramidal in general form (as it can be seen in section), and from the apex and lower parts there start off a great number of fine fibres which branch in a complicated way and have a structure peculiar to the cortex. From the middle point of the base of the cell there issues a prominent fibre, which is the axon of the cell, and branches pass off laterally from the axon and again branch. These are the "collateral" axons of the cell. Soon after leaving the latter the axons acquire medullary sheaths (see p. 26), and become the commissural or projection cortical fibres represented in

Fig. 28. Other fibres, commissural or projection ones, enter the part of the cortex in question and break up into terminal dendrites, which then come into relation with the apical and basal dendrites of the cell by means of synapses.

Thus each cell in the cortex can make a very great number of connections with other cortical cells, or with nerve cells in other parts of the central nervous system. Each of the collateral axons, for instance, can become a commissural or projection fibre, and a number of fibres coming from anywhere else can form synapses with the dendrites of any cortical cell. This is why the latter are so much more crowded in the canine, and still more so in the amphibian, than in the human cortex: there is the increasing tendency, as we raise in the scale of evolution, for the connections between the cells to become more and more numerous and complex, so that the number of paths which an impulse leaving a pyramidal cell may take tends always to increase.

The higher is the type of brain, the more manifold are the ways in which the various centres may communicate with each other.

Localisation of Function in the Cortex.—We must think of the activity of the cortex cerebri in a twofold way: it is one organ in so far as every part of it is connected with every other part, and it is multiple inasmuch as functions are specialised or localised in it. This specialisation has become known to us, partly by experiment upon the brains of the higher mammals (other than man), partly by the extension of these results to the human brain (which is, of course, very similar in structure to that of the anthropoid apes), and partly by observations made on human subjects suffering from disease and accidents.

Thus it is possible to distinguish in the human cortex a "motor region," which is concerned with the initiation and elaboration of willed movements; a "sensory region," upon which is dependent the full psychical development of the sensations arising from stimulation of the receptor organs; and a "prefrontal region," about the functions of which we have very little positive knowledge.

Fig. 38 represents the approximate positions and boundaries of the regions, and the particular areas into which the latter are divided. The two great fissures—those of Rolando and Sylvius—serve as lines which enable us to divide up the cortex into these regions and areas. One hemisphere (the left one) is seen from the side, but the reader must understand that the cortex dips down into the great median fissure that separates right and left

hemispheres, as well as into the Rolandic and Sylvian fissures, so that such a view as that of Fig. 38 does not show its entire area.

Round about, but mainly in front and in the depths of the fissure of Rolando, is the motor region, and this has been divided up into a number of particular areas, each of which controls the movements of some small part of the body. Thus, directly in front of the fissure are the "centres" or "areas" for the movements of the trunk, arm, hand, head and eyes, face, etc. These areas are not very well defined (for instance, they do not coincide exactly with the areas of the various "gyri" or convolutions), and they overlap to some extent. When any one of them is stimulated in a suitable manner, usually by application of

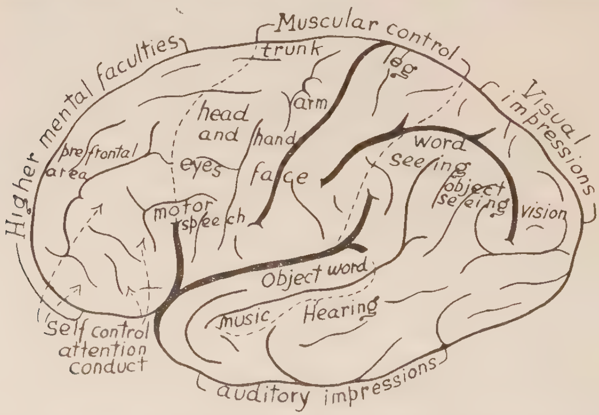

FIG. 38.—DIAGRAM OF THE PRINCIPAL CORTICAL CENTRES IN THE LEFT HUMAN CEREBRAL HEMISPHERE.

a feeble electric current, certain groups of muscles twitch or contract, and this is the evidence that the area in question controls these parts. The movements that are so elicited are not the finished ones that occur in the normal behaviour of the animal, but they indicate none the less the nature of the nervous controls and paths.

The cortex is, as we have seen, a thin sheet of grey matter overlying the core of nerve fibres that forms the greater part of the mass of the hemispheres. Directly beneath it we come upon the white matter, and much of this consists of the axons proceeding from the overlying pyramidal cells of the cortex. Tracing these fibres by various means, we find that they run down into the crura or cerebral peduncles towards the medulla. There, as Fig. 28 shows, these "pyramidal tracts" mainly cross each other, that one coming from the left-hand side of the brain

going over to the right-hand side of the medulla, and *vice versa.* The pyramidal tracts are then continued down the spinal cord, and there their fibres enter into the grey matter and form synapses with the nerve cells which give origin to the axons that go out into the ventral or motor roots of the spinal nerves.

Thus the grey matter of the motor region of the cortex is, on the one hand, in connection with fibres that run uninterruptedly down into the spinal cord and control the nervous centres there which set the muscles of the body and limbs in action. On the other hand, it is in connection with the centres in the other parts of the cortex which are the termini of the sensory paths.

But it is also in connection with the cerebellum *via* another specialised cortical region. Figs. 28 and 36 show a prominent tract of fibres descending from the cortex and ending in the region of the pons varolii—that is, the middle part of the middle peduncles which unite together the two halves of the cerebellum. Thus our cortical motor cells have communication with the nervous mechanism of co-ordination.

And just in the same way as the pyramidal tracts connect together the cortical and spinal nuclei, so do other more complicated paths connect the motor cortex with the medullary nuclei which give origin to the nerves that supply the muscles of the head and face. Thus every part of the motor system of the whole body is under the control of the cortex cerebri. This is particularly the case in man. In the fishes the great pyramidal tracts are hardly to be recognised, and they become developed to a progressively greater extent as we ascend the scale of evolution represented by the dog, monkeys, anthropoid apes, and man. In the lower vertebrates the nuclei which mediate between the organs of sense and the spinal ganglia are those in the mid-brain, but in the higher mammals this nervous mechanism becomes more and more replaced by the cortex and its connections.

Almost all the cortex behind the motor area is, as Fig. 38 indicates, the seat of sensory functions. Those centres called "visual," "auditory," "music," etc., contain pyramidal and other cells, the dendrites of which form synapses with the tracts of fibres coming up from the mid-brain nuclei in which the nerves coming from the organs of sense terminate. Stimulation of these cortical sensory centres is certainly essential to the development into full consciousness of the impulses arising from the stimulation of the sense organs. This is a matter to which we return in the following chapter.

CHAPTER VIII

THE ANALYSIS OF BEHAVIOUR

Our analysis of the nervous system has, so far, been that of a very complicated structure built up of superposed reflex arcs. A reflex arc is the series of nervous parts that connect together a receptor and an effector organ; thus the arc that is functional in the simple act of winking connects the retina of the eye with the visual centre in the mid-brain (by the optic nerve), the visual centre with the oculo-motor centre (by an intracerebral tract), and the oculo-motor centre with the muscles of the eye-lids (by the oculo-motor and facial nerves). When an action of any kind occurs, such a reflex arc or arcs become functional. The receptor organ receives a stimulus—that is, something happens outside the body: a flash of light, a noise, a current of air carrying odoriferous particles in suspension, etc.—and this event causes some change in the receptor organ. The nerve terminations in the retina, the internal ear, or the mucous membrane of the nose are thus stimulated, and they initiate a nervous impulse which is propagated along the sensory nerve to the centres of the brain.

There the afferent nervous impulse breaks upon a series of synapses, and so enters a number of nerve cells that constitute the centre (or nucleus, or ganglion). Something now happens to the impulse in these cells, and its physical nature is doubtless changed in some way. At any rate it is transferred from the cells to the axons which come from the latter. Those axons constitute a nervous tract leading to another nucleus, where there is also a series of synapses. The impulse, after further modification in the cells of the second nucleus, is now transferred to an efferent nervous tract which is constituted by the axons passing out from those cells. After traversing this third nervous tract (or effector nerve), the impulse is received by the effector organ. Let us suppose that this is a muscle. The latter thereupon contracts or relaxes.

This is a scheme of what happens whenever a bodily action occurs: a stimulus is initiated and propagated along an afferent

nerve into the central nervous system. It is there prolonged through an efferent nerve into the effector organ, where it releases energy.

Now we may try to make a " mechanical model " of this train of events, premising that whatever it may be that occurs in the actual nervous arc it is sure to be (physically) very different from the things that happen when our model is set in action, *but that the energy relations in the actual muscle-nerve structures and the parts of the model will be the same.* Suppose, then, that a number of billiard balls, a to g, are suspended by threads so that they almost touch each other; let another ball, h, be poised on the end of a tipless cue. Let the end ball, a, be pulled a little to one side, and then let go so that it hits b very gently. Further, we may assume (as it is generally assumed when logical hypotheses or mechanical models are made) that the balls are perfectly elastic (which they nearly are), and that there is no friction in their suspensions.

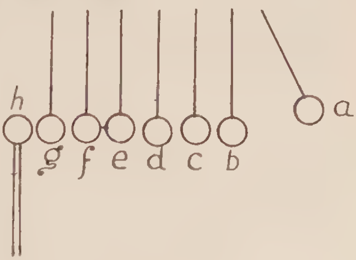

Fig. 39.

The ball a will then communicate momentum to b, and cause b to hit c, c to hit d, and so on; c will communicate as much energy to d as it received from b, and a wave of mechanical displacement will travel along the row. The ball g will hit h with as much force in the blow as a has hit b, and the blow will cause h to roll off its perch and drop to the floor.

Suppose still further that a has been lifted up $\frac{1}{2}$ inch; that the weight of each ball is $\frac{1}{3}$ pound; and that the height of h above the floor is 6 feet. Now, in falling through $\frac{1}{2}$ inch a does work equal to its weight $\times$ the distance through which it falls—that is, $\frac{1}{24}\times\frac{1}{3}=\frac{1}{72}$ foot-pound. The quantity of energy so represented is " propagated " along the row of balls and communicated to h, and is just sufficient to push the latter off the end of the cue on which it is poised. It then falls 6 feet, and so does work equal to $6\times\frac{1}{3}=2$ foot-pounds. Prior to being displaced it had this quantity of potential energy due to its having been lifted from the floor and put in such a position that it was free to fall 6 feet. A small quantity of energy representing $\frac{1}{72}$ foot-pound of work can therefore be propagated without loss, and can release a much larger quantity—that is, 2 foot-pounds.

What we know about the passage of a nervous impulse along a nerve suggests that the former passes without any of the substance of the nerve being used up. Arriving at the first synapses, it passes into the nerve cells there and transforms into the same quantity of energy, which then passes along the intra-cerebral tract into the second synapses and cells, where another equal quantity of energy is transformed and is propagated along the efferent nerve (again without loss), and thrown into the muscle. But there it releases a much greater quantity of energy, which is represented by the force with which the muscle contracts or relaxes. The latter contained energy in the potential (chemical) form, and the minute quantity entering it as a nervous impulse sets free or transforms this chemical energy in the same way as a small electric current can release (or fire) the huge quantity of energy contained in an explosive charge.

Now, from the point of view that we have taken so far, everything that happens in the sensori-motor system of an animal conforms to the structural scheme of reflex arcs and to the dynamical scheme of the billiard-ball model. The peripheral and central nervous system is a means whereby the energy received by the stimulation of the receptor organs is transmitted as a nervous impulse to the nerve centres, and is there transformed into another kind of impulse which is transmitted to an effector organ, where, finally, potential chemical energy is released, and muscles contract and relax or glands secrete. The impulse which results from the stimulation of a sense organ goes to the central nervous system, but there it may pass along one or more of a great number of different paths. Upon the path it takes depends its effect; thus the stimulation of the retina may lead to a reflex act of winking, or the "mouth may water," or the man may start violently, or run, or sit down, or laugh. Nothing, then, is explained by our structural analysis of the nervous system; all that we have studied is the means whereby one of a number of effects that may be produced by a stimulus is produced.

Consider now the energetical side of the process of stimulus and response. Just that quantity of energy which is received by the receptor organ is transmitted along the afferent nerve into the centre, and the same quantity again is sent through the central nervous system from centre to centre, and still the same quantity is transmitted along the efferent nerve into the effector

organ, where it is all expended on releasing the potential energy which is to produce the effect in question. Or suppose (for it does not matter to our argument in the least) that some of the energy entering the sensori-motor system is dissipated, or wasted, or "lost" by "friction" (as some would actually be "lost" in the billiard-ball model). This dissipated energy will therefore appear in the form of heat, and the rest will be transmitted as before to the effector organ. Where, then, does the consciousness of having seen something and acted upon the stimulus so received come from? For we must consider the suggestion that an affection of consciousness is the result of an energy transformation; that it comes from the energy of light that stimulated the retina and transformed into a nervous impulse just in the same way as the heating of a metallic filament is the result of the transformation of an electric current which passes through a lamp.

We are not going to accept this suggestion, but we notice it in order that the reader may see quite clearly what are the various possibilities (let us say):

(1) All the energy that comes from without the body and stimulates a sense organ is transmitted without loss through the peripheral and central nervous system, and is physically transformed in the effector organ, releasing potential energy there which does work.

(2) Some of it is dissipated, and the rest is transmitted as above.

(3) Some of it is transmitted as in (1), with or without dissipation, and some of it is physically transformed into "consciousness."

Now what we know suggests that there is extremely little or even no dissipation of energy in the transmission of a nervous impulse through a reflex arc. And the more we think about the third of our three hypotheses, the more unlikely it appears to be. At all events, it does not seem possible even to attempt to verify it.

We return to this discussion in a later chapter. Meanwhile, let the reader note that all that we have studied so far—all, indeed, that it appears that cerebral physiology can study—are the ways in which the stimulation of the organs of sense set up nervous impulses, the paths along which those impulses travel in the central nervous system, and the motor and secretory effects that they produce. There is nothing at all about a theory of knowledge in the results of such an investigation, but very much about a theory of action. Sensation is not something that enables us to contemplate the external world, but is rather that

which enables us to *act* upon the latter. It is not so much prolonged or developed into consciousness of our environment as into action upon the environment.

We must deal further with this aspect of physiology.

Stimulus and Response in General.

We consider again a "mechanical model." Let there be a little compass, *NS*, placed in the neighbourhood of a wire into which an electric current may be thrown by depressing a switch. So long as the current does not flow through the conductor, the needle remains in the position *NS*—that is, in the magnetic meridian; but whenever the switch is put down and the current passes in the (conventional) direction indicated by the arrow, the compass needle deviates and takes up the new position *WE*. When the current is switched off the needle returns to *NS*, and no matter how often we do this the effect is always the same. Now call the making contact in the switch a "stimulus" and the deviation of the needle the "response"; the latter, we see, is invariable and inevitable. Given that the same quantity of current flows through the conductor, and that the intensity of the earth's magnetic field remains constant, then the needle always deviates in the same direction and to the same extent. There is strict *determinism*—that is, the "response" (a certain deviation) always follows upon the "stimulus" (a current of a certain value).

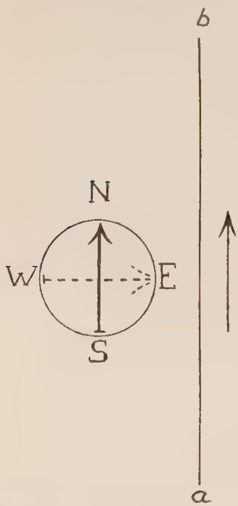

FIG. 40.—A COMPASS NEEDLE, *NS*, LAID ALONGSIDE A WIRE, *ab*, THROUGH WHICH A CURRENT CAN BE PASSED.

The Muscle-Nerve Preparation.—Now let the prominent thigh muscle (gastrocnemius) in the frog's leg be dissected out, leaving its tendon still attached to the femur and an inch of its nerve (the sciatic) attached to the muscle which carries a weight. Place two electrodes carrying a current in contact with the nerve. Throw a momentary electric current into the circuit containing the electrodes, and the nerve will be stimulated at the place *a*. The stimulus initiates an impulse which traverses the nerve and releases potential energy in the muscle, whereupon the

latter contracts, lifting the weight against the resistance of gravity. Do this again and again, and the same effect follows. By-and-by the muscle, or the nerve terminations in it, will become fatigued, but until this happens an electric stimulus will always elicit the same muscular contraction or response. Here, also, there is, perhaps, strict determinism.

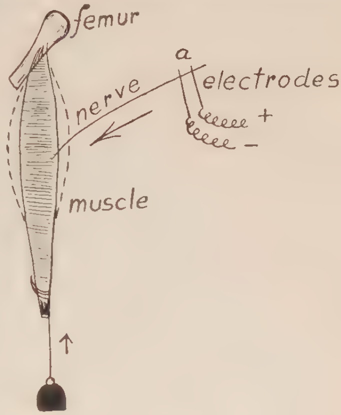

Fig. 41.

Tropisms in Green Plants.—When a seed germinates, two structures grow out from it. One of these is the original root and the other is the original shoot. The former always grows down into the soil, and the latter grows upwards into the air. When a green plant is placed in front of a window, the leaves tend to turn towards the source of the light. The leaves of a tree tend always to place themselves so that their flat surfaces are perpendicular to the principal direction from which the light comes. All these effects are called "tropisms," or directed growth movements of fixed organisms. The tissues of the plant have the general power of growth, but the stimulus of light falling on them is a directive agency, which causes growth to take place in one direction rather than any others. Such directed growth movements in response to the stimulus of light are called *heliotropisms*. They are invariable and subject to determinism, just as are the deviation of the compass needle or the contraction of the isolated frog's muscle when the nerve supplying it is stimulated.

Taxis in the Lower Animals.—Chip off some barnacles (*Balanus*) from the stones on the beach between tide-marks during the last week of March or the first ones of April, and place them in a soup-plate containing clean sea-water. In a short time the embryos contained in the reproductive organs will hatch out and swim about in the water. Examine the latter in a feeble, diffused light, and it will be seen that the larvæ swim about at random and in no particular direction; but place a lamp close to one side of the vessel, and it will be seen that they swim

towards the point from which most light comes. This response is called a *phototaxis*, and it may be defined as the directed movements of an organism in response to a directed light stimulus. It is invariable and determined, and a logical hypothesis—that is, one which is consistent with what we know about light and its general effect on living tissues—can be made to account for it.

The Spinal Reflex Action.—"Pith" a frog—that is, cut through the spinal cord—immediately behind the brain, and then destroy the latter by pushing a blunt wire into it. The body of the animal is now solely under the control of the spinal cord and its ganglia; to convince oneself that this is the case, the head may be removed. If, now (or, rather, after the effects of the "shock" have passed off), a drop of strong vinegar be placed on the back of the animal, one of the hind-legs will be bent forward and the acid will be wiped off. A reflex arc of some complexity is here involved: afferent impulses pass into the spinal cord from the receptors in the skin irritated by the acid, and these impulses are received by the nerve cells in the segment of the cord which innervates the part of the skin stimulated.

From the segment stimulated tracts of fibres convey the impulses received to the grey matter of the segments from which the legs are supplied with motor nerves. The latter are then stimulated, and the antagonistic muscles contract and relax, carrying out the series of movements described (Fig. 42).

Now here, again, there is determinism, or, at least, the results of stimulating the skin can be predicted. But there is now a difference between the response in this case and the "mechanically" repeated one that occurs in the muscle-nerve preparation: when the drop of acid is placed on the right flank of the headless frog, the right leg is used to wipe it off. Now let this leg be cut away or forcibly held, and the left one is used to make the same kind of response. Something occurs, then, in this case which we have not, so far, observed. Evidently there are two mechanisms, one for each side of the body, but in what we may call ordinary circumstances one of them is passive. Let, however, the "normal" mechanism be prevented from operating, and then that one which was passive before now responds vicariously. We have to deal here with a "regulation."

Such a "spinal reflex"—that is, a co-ordinated action carried out by the nervous ganglia of the cord—can be elicited from higher animals than the frog. When the cord is severed in the

dog and the effects of the shock of the operation have passed away, suitable stimulation of the skin of the side just behind the shoulder is followed by the response called the "scratch reflex": the hind-leg of the same side carries out a series of kicking movements somewhat similar to those performed when the normal animal scratches himself as the result of irritation by a flea. Even in man something of the same kind may occur. Thus, in cases of hemiplegia, when the connection of the cortex

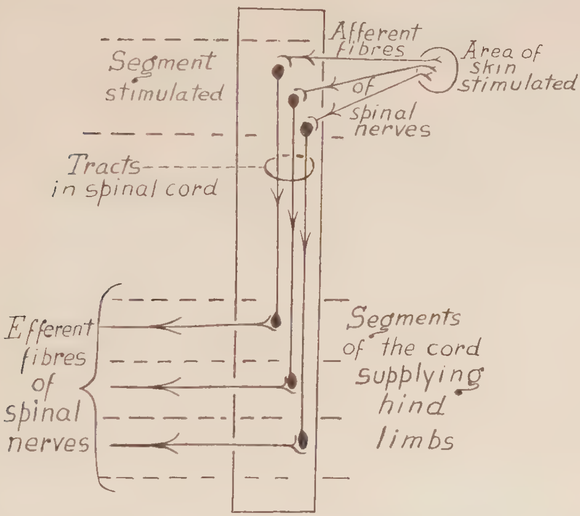

FIG. 42.—THE "SCHEMATIC" SPINAL REFLEX, BEING THE NERVOUS PATHS INCLUDED WHEN THE STIMULUS IS THROWN INTO A DIFFERENT SEGMENT FROM THAT INNERVATING THE MUSCLES THAT ACT.

with the cord is rendered ineffective by a "stroke," reflexes in the paralysed leg may be obtained, and these are doubtless due to the centres in the spinal cord.

Reflex actions, complex and purposeful in character, may thus be carried out by the nerve centres in the spinal cord.

In such cases the stimuli (irritation by chemical substance, an electric current, mechanical pinching, pricking, etc.) applied to the skin are simple physical ones, and the response is generally such an action as would be carried out by the muscles concerned, in the normal animal, for some useful purpose. It always has a certain "inevitability"—that is, it "comes off," as a rule, when the stimulus is applied. There is determinism, or at least a large measure of determinism. It can usually be predicted.

Reflexes in the Normal Animal.—Now compare with these spinal reflexes those that may be observed in the normal, intact animals. Such a response is easily observed in the case of a dog which is lying sleeping on his side with his legs stretched out. When the skin over the ribs is rubbed vigorously, the hind-leg of the same side will often make a series of foolish little kicks, like incipient scratching movements. We may even study such reflexes in ourselves. We usually start violently on hearing a loud, unexpected noise, and the muscular actions involved have meaning, inasmuch as they seem to be such as would place the body in a posture of defence to meet some sudden menace. When some object makes an unexpected movement towards the eyes the lids are rapidly closed, and here also the action has purpose—the protection of the eyes. As a general rule these and similar responses are quite involuntary, and it may even require some considerable effort of the will to arrest or prevent them. But that they can be arrested or prevented is the characteristic that distinguishes them from the reflexes which are carried out by the spinal cord alone in the lower vertebrates or in the higher vertebrates deprived of their cerebral hemispheres. Even the sleeping dog will not always give the incipient scratch reflex when his side is rubbed, and by strong attention and " will-power " a man may keep his eyes open when someone flicks some object towards the face, or when he puts his head underneath water, and one may easily arrest the start that he naturally makes when he hears a loud, unexpected noise.

This point is very important. The response that may be elicited by a stimulus applied to the animal possessing its integral nervous system is not a " fatal " or " inevitable " one. It may occur, but it may not. It may occur in one of several ways, and it may occur and immediately be arrested. All that means that the strict physical determinism that one sees in the " response " or deviation of a compass needle when a magnet is brought near to it, or the equally determined tropistic and tactic responses of the lower organisms, or the spinal animal, do not occur in the higher vertebrate possessing its entire central nervous system. In the responses that one studies in such cases there is always what we must call indeterminism: they are usually unpredictable.

But while this is the case, it is no less clear that we can study a series of responses beginning with the purely inorganic reaction of the compass needle and magnet, and passing through the

muscle-nerve response, tropisms, taxis, reflexes, in animals subjected to various kinds of operative interference, and ending with the behaviour of the normal, intact higher animal. At the beginning of such a series there is determinism, and at its end there is indeterminism; but it would be rather difficult to suggest any place where determined reaction became replaced by some degree of chosen, deliberated behaviour. In such a series of organic mechanisms we should be able to trace the beginning and the gradual elaboration of a central nervous system. Nothing of the kind is, of course, present in the compass-needle-magnet system, and it is very doubtful if it can be recognised in the typical plant organism. It is present in a very simple form (far simpler than that which we have represented as present in the earthworm) in the barnacle larva, and it becomes progressively more complex as we ascend the vertebrate series. Somewhere, then, in the ascending scale of living things indeterminism of response is developed; we emphasise the word "response" so that it may not appear that we exclude indeterminism of functioning in the most general sense from the lower organisms.

The Lower Brain Activities.

We may next consider how the reactions exhibited by an animal are modified when certain parts of the brain are removed, or isolated from the other parts. Now, in such an animal as the frog, both the cerebellum and the cerebral hemispheres are undeveloped relatively to the medulla and mid-brain. The former organ may be called rudimentary, and the cerebrum consists of the two corpora striata, each with a rudimentary cortex cerebri. It is an easy matter to remove the two cerebral hemispheres (including the corpora striata), and the animal survives the operation. It is then in possession of a central nervous system, including the parts developed from the three primary brain vesicles, but lacking the fully developed cerebellum which is present in most vertebrate animals higher than the reptiles.

Now every action that can be performed by the intact frog can equally well be performed by the decerebrate frog *provided that a suitable stimulus be applied.* It can swim, leap, and crawl, and it assumes, when motionless, the natural posture of a frog. It can avoid obstacles when it is moving, and it is sensitive to light. Its visceral, respiratory, and nutritive organs function normally. It swallows food which is placed in its mouth. If

it is turned over on to its back it can regain its proper attitude.

But it does none of those things spontaneously, and if it is not stimulated it makes none, or very few, movements of its own accord, and it nearly always remains in exactly the same position if it is left strictly alone. When it is stimulated it responds in an almost invariable way, and the effect of any particular stimulus can be predicted. What is wanting in its reactions and movements is the evidence of spontaneity: there is no "intrinsic stimulus," and nothing that indicates the possession of volition. It is "a machine, and nothing more, while the frog possessing its cerebral hemispheres is a machine governed and checked by a dominant volition."

Its responses to external stimuli indicate that it possesses the power of completely co-ordinating its movements. That power, we shall see, is dependent in higher vertebrates on the presence of the cerebellum, and on the full connections of this organ with the rest of the nervous system. But in the frog the cerebellum is rudimentary, and we must therefore conclude that the functions that it performs in the higher vertebrates are carried out by the mid-brain. Therefore we cannot say that co-ordination is the work of the cerebellum exclusively in all vertebrates. It can be effected by other parts of the brain.

Now remove the cerebral hemispheres—that is, the corpora striata and pallia—from a fish, and the animal survives the operation. But there is no absence, "not even the temporary absence," of apparently spontaneous movements. It is therefore evident that spontaneity of behaviour, which depends, in the frog, upon the presence of the cerebral hemispheres, can be mediated, in the fish, by the mid and hind brain, just as co-ordinated movements, which depend, in the bird, upon the presence of the cerebellum, can be mediated by the mid-brain in the frog.

The cerebral hemipheres are much more highly developed in the birds than in the amphibia, but they can be removed and the animal (the pigeon) can be kept alive for a considerable time after the operation. The same general effects observed in the frog can also be seen in the decerebrate bird. It either remains quiet and impassive, or it moves about restlessly and without any apparent purpose. *Of itself* it does not attempt to fly, but if it is thrown into the air it will fly and avoid obstacles. It does not spontaneously pick up corn, though it will do so if its

beak is thrust among the grain. Like the frog, it responds to stimuli, and it sees and hears in so far as seeing and hearing are the stimuli to movements; but sight and hearing do not, apparently, evoke memories or utilise experience. Its movements are perfectly co-ordinated. There is the same inevitable response to external stimuli, the same automatism of activity, and the same lack of spontaneity and volition (which latter is indicated by spontaneity) that we see in the decerebrate frog.

Among the mammals the cerebral hemispheres are much more highly developed, again, than in the bird, and their removal is a formidable operation. Yet it has been accomplished in the dog, and when the animal is nursed with the utmost care and solicitude it may survive for over a year. In the few successful experiments that have been made there has been some little difficulty in exactly describing the condition of the patients. As in the frog and bird, there is no paralysis and no lack of co-ordination so long as the cerebellum is intact. All ordinary movements are carried out, and, as in the bird, there is a tendency to restlessness. The sense organs are active in so far as the motor organs can respond to ordinary sensory stimuli, but things that would, in the intact dog, evoke expressions of terror, dislike, and pleasure, do not appear to affect the decerebrate animal in anything like the same degree. Signs of hunger are exhibited, and food brought near to the nose is eaten. Disagreeable food may be rejected (for instance, one of Golz's dogs would not eat the flesh of another dog). Both in decerebrate dogs and cats painful stimulation elicited expressions of anger (growling, barking, and snarling), but no caressing could evoke any indications of pleasure or affection. There was apparently no dreaming. Finally (a most curious thing), Golz's dog ate much more than the normal animal did.

Nervous Inhibition.

We must say more about these results. In the decerebrate mammal there is the same lack of spontaneous activity as in the frog and bird, understanding by this the absence of apparently willed, or deliberated, or intelligent, or chosen activities, and not the aimless, automatic activity to which we referred above as "restlessness." There is the same tendency for a stimulus to evoke an inevitable response—the actions of the animal can be predicted. But the inhibitions are still more interesting.

A nervous inhibition is the arrest, entire or partial, of some activity in progress, and such effects are very common and very important. The rhythmic activity of the heart, for instance, is intrinsic—that is, it apparently goes on as the result of some periodic stimulus originating in its own substance. But this rhythmic activity is subject to nervous control, the heart-beat being regulated by two sets of nerves, one coming from the sympathetic system, and the other from the tenth (pneumogastric or vagus) nerve. The stimulation of the former accelerates, and that of the latter inhibits, the rate of the heart, so that, by suitable stimulation of the vagus, the beat may be slowed down or may even be arrested altogether.

Now nervous " shock "—that is, the great prostration arising from an injury, or the effects of a surgical operation—is to be regarded as a series of inhibitions. In some way or other impulses passing down from the higher brain centres are blocked (as when the spinal cord is severed), or are not initiated (probably as the result of afferent stimulation in the case of a severe injury), and the stopping of these impulses is the main cause of the prostration and other effects called " shock." In the decerebrate mammal, then, impulses that normally issued from the cortex cerebri cease, and the general activities of the animal are affected. The restlessness referred to above may be traced to the cessation of inhibitory impulses which in normal life arrest or modify aimless, random movements. The abnormally large consumption of food may also be traced to the cessation of cortical impulses regulating the metabolism of the tissues and economising energy, and the condition that anger and dislike could be elicited, but not pleasure and affection, may also be traceable to the loss of inhibitions.

For one may (taking a general survey of organic behaviour) conclude that the feral animal has normally a " bad time." It struggles for its existence both with inorganic nature and with its organic enemies. It must " eat or be eaten." " Softness of heart," dalliance, pity for others, and the like, are feelings that are wanting, or, if present, are likely to be detrimental or fatal, while their opposites make for self-preservation. What we call loosely the altruistic motives must be regarded as the product of the herd instinct, and they are to be interpreted as inhibitions or checks upon the natural, predatory, and highly individualistic modes of behaviour. They are opposed to most tendencies that

are the products of natural selection, as a study of adaptations among wild animals will show. Insanity in man that is not the result of lesions, it has been argued, is to be interpreted as conflict between the mental complexes that the struggle for existence has engendered on the one hand, and those newer complexes that arise from the development of the herd instinct on the other. As in Mr. Wells's *Island of Dr. Moreau*, there is a "law" (a series of inhibitions) which comes into tragic antagonism with the naturally evolved animal propensities.

And so, lacking the inhibitory controls acquired by domestication and centred in its cortex, Golz's dog could growl and bark, and manifest anger and displeasure, but not affection—which to it was something quite secondary—an inhibition of the "currish" nature of the natural dog.

And so also a study of social evolution and of mass psychology impels one to the conclusion that what we recognise as "good" is mostly the inhibition of what we may call the lower animal instincts that are in us. The result is, of course, clearly demonstrable in much of our conduct, for our codes of private and public morality are, to a great extent, summaries of the things that may not be done—inhibitions—and which the natural man would often like to do; while our legal systems supply the sanctions for those prohibitions and restrictions. What are called "socialist tendencies" are, of course, attempted inhibitions of individualism. The ruthlessness that characterised German methods of warfare far more than those of their opponents was the result of a slackening of inhibitions, a disregard of the amenities of armed conflict (the things that might not be done), and as such it met with general reprobation. The "war psychoses" of European countries during and after the year 1919 illustrate the same proposition: one cannot help noticing a tendency to increased dislike of people belonging to other nationalities than our own, and a general indifference to suffering borne by other peoples. Those feelings were potential in us before the war, but they were repressed, and the strains set up by the necessity for natural self-preservation loosened the inhibition and allowed of their expression.

The Cortex Cerebri.

From what has already been said about the progressive development of the cerebral hemisphere in the vertebrate animals the reader will see that we ought not to speak about "the"

cortex. It is not the same thing in the mammals as it is in the birds and reptiles, where it is a more complex organ than it is in the amphibians, and it does not occur at all among the fishes. This disparity of development must always be remembered when we discuss the functions of the cerebral hemispheres so far as these can be made out from observations of the effects of operative interference. Removal has little or no apparent effect in a fish, where the "cortex" is non-nervous, but the result is very obvious in the frog, and still more so in mammals such as the rat, rabbit, and dog. In the monkeys and apes, and, of course, in man, the operation is an impossible one, for these animals do not survive it long enough to make clinical study profitable.

In lower vertebrates, such as the frog, the cortex is relatively unimportant (judged from the anatomical standpoint) when it is compared with the rest of the brain, and the functions that it subserves are also unimportant. When it is removed the change of behaviour is not a profound one, and it is possible that some of the things that were formerly done by the cerebral hemispheres are then done (or partially done) by the mid-brain. To some extent this is also the case with the dog, where vicarious functioning on the part of the lower brain may be set up when the cortex is removed. That such is the case is suggested by the observation that animals deprived of their cerebral hemispheres tend to act more normally the longer they can be kept alive and in good general health. Now, in the monkeys and anthropoid apes, the development of the means of control over acting by the cortex has been carried so far that vicarious functioning by the mid-brain and thalami become impossible, and this is still more the case with man.

Reviewing the bare summary of the evidence that has been made here we see, however, that with the removal of the cortex cerebri spontaneous movements tend to disappear, while automatic and mechanical activities persist. The animal so treated reacts to stimuli in a blind, inevitable manner,so that its responses can be predicted. There is physical determinism—at any rate, much more of such than in the intact, cerebrate animal. Our only criterion of volition, deliberation, and intelligence is this presence of spontaneous behaviour, and therefore we are justified in placing the immediate expressions of will and intelligence in the activities of the cortical mechanisms.

The Nervous System as a Whole.

Having made this very bare analysis of the structure of the central nervous system, we are now in a position to consider its working as a whole, but, first of all, we may profitably think about it as a series of superposed mechanisms, thus following the natural path of evolution. Fundamentally, then, the nervous system mediates between the stimulation of the organs of sense on the one hand, and the organs of activity on the other.

Some physical change in the environment leads to the stimulation of a receptor organ, and the initiation of a nervous impulse. The latter is received by the nerve cells in the ganglion, and in its

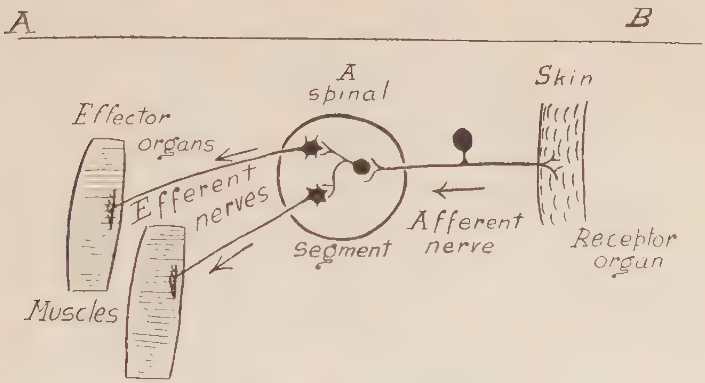

FIG. 43.—THE SIMPLEST POSSIBLE SENSORI-MOTOR ACTIVITY.

A spinal reflex mechanism, the line *AB*, represents the junction of spinal cord and medulla.

turn initiates a number of impulses which pass out from the ganglion along efferent nerves and set up a co-ordinated and purposeful activity in the muscles to which those nerves go. There need not be (and there usually is not) any perception in such a stimulus and response. The latter is usually determined, and can be predicted.

Next, the development of the special sense organs in the head, and the concentration of ganglia there, lead to a certain integration of sensory stimuli and their resulting responses. The head ganglia were primarily the centres, or nuclei, of the great organs of sense, but it happens they also become connected with the lower spinal centres, as we have indicated in Fig. 28, and so we get a superposed series of connections.

The mediating mechanism is now greatly complicated, inasmuch as the receptor organs which are in primary connection with the spinal ganglia are also in connection with the ganglia of the organs of special sense in the head, and there are also motor paths between the mid-brain and the cord. Obviously actions immediately carried out by the motor centres in the cord can now become more complex, and may be co-ordinated to a greater extènt because of the additional stimuli given by the special

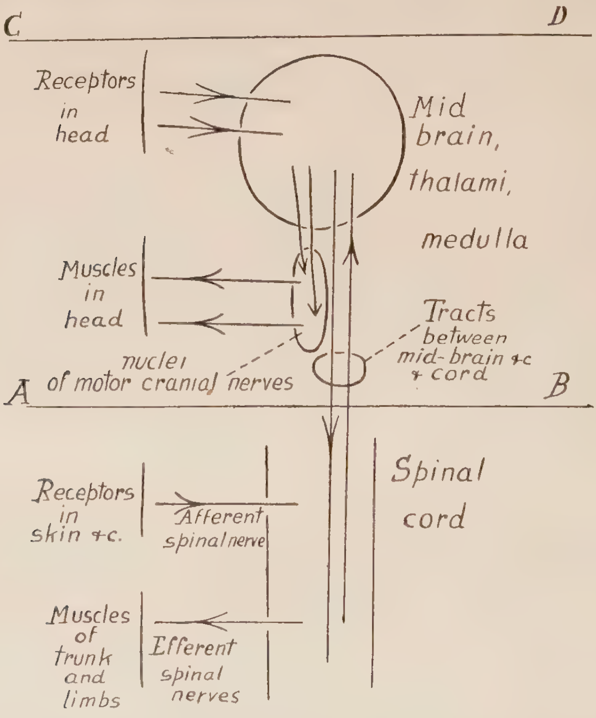

FIG. 44.—MAIN PATHS BETWEEN SPINAL CORD AND LOWER BRAIN.

sense organs. Still, the responses may largely be automatic and inevitable ones, although there must be some subtle difference in them when compared with the purely spinal reactions.

Such a structure and relationships are, in general, those of the fish, where the cortex is absent and the cerebellum is rudimentary. Now consider the additional complexity which is brought about by the development of the cerebral hemispheres and cerebellum, organs which have evolved simultaneously, or nearly so.

Neglecting the intermediate stages of this evolution (for we

know relatively little of the nerve tracts in the brains of the amphibia, reptiles, and birds), we may consider the conditions in man. We have already indicated the connections between the cord, cerebellum, mid-brain, and cortex, but a purely schematic figure will be useful. Fig. 44, then, represents the main communications between the mid-brain and spinal cord. The parts

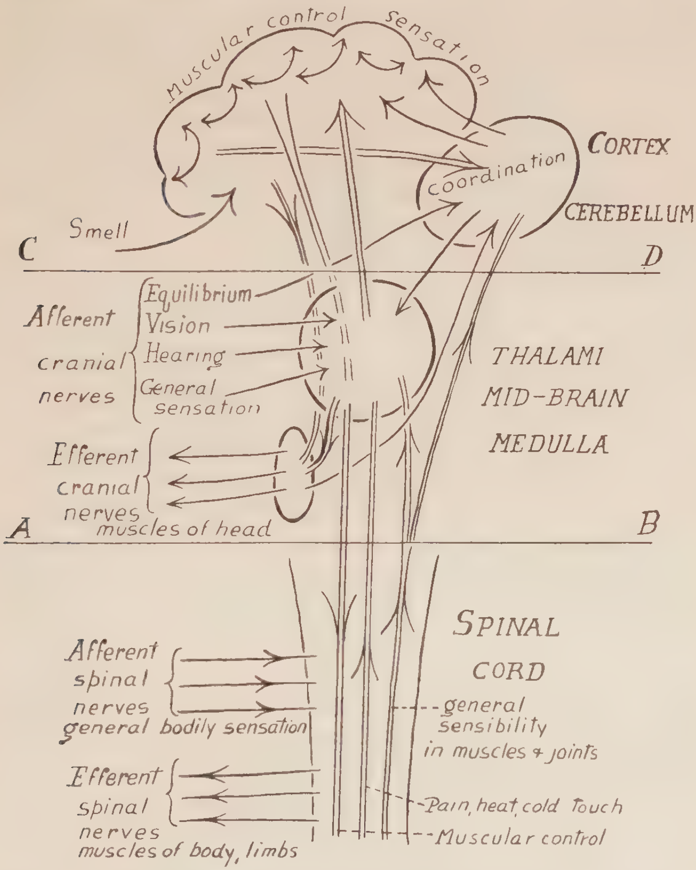

Fig. 45.—Main Paths in the Nervous System as a Whole.

below the line, *AB*, we regard as the simple, primitive, central, nervous system, such as it probably was in the ancestors of the vertebrates, while the parts above *AB* represent the additional connections established when the great sense organs of the head have become evolved. In Fig. 45 we add the mechanisms involved in the cerebellum and cerebral hemispheres.

Now, but for two exceptional paths—that of the impulses passing directly into the cerebral hemispheres through the olfactory nerves, and that of the impulses going to the cerebellum from the vestibular part of the auditory organ—the parts represented above the line *CD* in Fig. 45 connect together the various components of the central nervous system—*they are the integrating mechanisms.*

Thus the cerebellum receives impulses directly from the muscles and joints of the body and others indirectly (*via* the mid-brain) from the skin; it receives impulses indirectly (also *via* the mid-brain) from the organs of special sense in the head, and it is in direct (to and from) communication with the cortex. And so it has a grip on all the afferent impulses, whether those of general or special sensation, arising anywhere in the body.

The cerebral cortex has conspicuous connections with the cerebellum, as we have just said, but the communications with the nuclei of the mid-brain, in which the nerves of sense end, are just as prominent, and the great pyramidal tract leading down from the motor region of the cortex to the nuclei of the motor spinal nerves is more conspicuous still. And so the grip of the cortex cerebri on both receptor and effector organs is as evident as that of the cerebellum on the receptor organs.

We may now resume the general working of this whole mechanism. The parts below the line *AB* constitute relatively simple reflex arcs sufficient in themselves for movements initiated by the stimulation of the sense organs in the limbs and trunk. The parts between *AB* and *CD*—that is, the mid-brain complex—also form reflex arcs, but the distance receptors (visual and auditory organs) are now included, and become incorporated with the spinal arcs by means of the tracts joining mid-brain and cord. The stimuli initiating movements are now much more varied and numerous, and so the latter become more complex than when they depend on the cord alone.

Finally, when the parts above *CD* are fully evolved, something quite new is added to the activities of the central nervous system. The cerebellum mediates between the impulses coming from the receptors in general (but particularly those in the muscles and joints), and the impulses that pass out from the cortex to set muscular mechanisms in action. It is not concerned in the psychical life of the animal to any degree that can be recognised, but it "standardises" and co-ordinates a number of very com-

plex movements performed in a customary manner—those of locomotion and posture. Something additional to this is effected in the cortex. Looking at the main features of the anatomy of the latter, we see the extraordinary development of the motor region and the tract of fibres connecting this with the spinal nerve nuclei, and studying the results obtained clinically (in the case of man) and experimentally (in the case of other mammalia), we see that the movements most suggestively connected with cortex and pyramidal tracts are of a special kind: they are skilled movements, and the facility to make them is acquired by training and is individual—that is, they are not transmitted by heredity. Further, they are usually spontaneous movements, or at least they are such when they are being learned.

Looking again at anatomical, experimental, and clinical results, we see that the cortex is to be associated with sensation that develops into consciousness. The connections between it and the sensory nuclei in the mid-brain are very obvious, and all observational results point to the same conclusions. We return to this matter in a later chapter.

The Meaning of Behaviour.

We define " behaviour " (premising that we are now dealing with the higher animals) as the totality of the activities of the *entire* sensori-motor system—a definition which, however, must not be strained. It excludes the activities of the viscera (heart and bloodvessels, respiratory, nutritive, and excretory organs) because these are subsidiary to the proper functioning of the sensori-motor system. It excludes the activities of the reproductive organs, because it is the individual animal that we are studying, and not the race. In behaviour in general we see the activity of the entire motor system, as in running, walking, swimming, flying, and other modes of locomotion, as well as the partial activities of bodily weapons, as in biting, clawing, etc. It would include the actions of defence, flight, concealment, aggression, the construction of nests and shelters, etc. It must also include the actions carried out in play, courtship, etc., and generally the " behaving " of the animal in the ordinary, non-technical sense of the word.

Organic behaviour is to be regarded biologically as constituting a series of *adaptations.* The things that occur in the outer world cannot, in general, be prevented by the animal living

there. Thus the succession of day and night, the order of the seasons, changes in weather, such as storms, gradual or catastrophic geological changes, the vicissitudes of climate, tides, ocean currents, winds, etc.—all these things are phases in a "cosmic order," and are beyond the control of the feral animal, or even of man. All that the organism can do is to avoid menace to itself, or to take advantage of external changes in so far as it can do so by some variation of bodily functioning. The real meaning of the evolutionary process, from the biological point of view, is the slow acquirement by the organism of the means of varying its functioning, so that it can evade external changes that are inimical to it or take advantage of other changes.

When winter comes, many arctic animals respond to the external changes by a change in the colour of the fur, say, from brown to white. This renders them less conspicuous in a snow-covered country, and the animal obtains an advantage in that it is less easily seen by its enemies, and can the more easily approach other animals that are its natural prey. Many fishes and other animals hibernate during cold weather—that is, they seek shelter of some kind, and lie in a passive condition, economising muscular movements as much as possible. The respiratory and heart movements slow down. Oxidation of the tissues is partially inhibited, and the animal lives on its reserves of fat and proteid. The advantage gained in such cases is that the animal is spared the necessity of seeking food at a time when this is very scarce. When a man passes rather suddenly from a tropical into a temperate climate, he excretes much less water from his skin and much more through his kidneys, and he thus economises heat by an inhibition of evaporation of sweat. These are instances of adaptations of the functioning of organs other than those belonging to the sensori-motor system, and they do not involve "psychological factors"—that is, they would be possible in the absence of the higher parts of the brain, or at least they need not include the activities of the latter organs. They do not constitute behaviour.

Neither do many adaptations that we call instinctive ones. Thus the blowfly lays its eggs in fresh meat, so that when the larvæ hatch out they may obtain abundant nutriment. A bird builds its nest in such a place and in such a way that it is difficult to distinguish it from the surrounding objects, and so the concealment of the eggs and young is an advantage. A crab casts

its shell, and for a time it is almost unprotected against many natural enemies. In such cases it seeks shelter in a crevice among the stones or weed on the sea floor, and so conceals itself. These are examples of responses involving the activity of the sensori-motor system, but they are fixed, " mechanical " ones that have become part of the organisation of the animals displaying them; they are transmissible by heredity, and they do not have to be acquired individually. It is true that they must have been acquired some time or other, but in a different way from the cases which we are about to mention.

Young chicks learn to distinguish between small stones and grains of corn. Collie dogs find that they ought to leave sheep alone, and soon do so. Retrievers pick up, and bring back, game without crushing or eating it. Cats and dogs learn to open latches, to beg for food, and to recognise people who take notice of them. A man puts on an overcoat when the weather becomes cold, and the master of a ship alters his course when a sudden fall of the barometer in certain latitudes suggests that a cyclonic storm is approaching. These are all true adaptations, and each of them ends in the animal obtaining advantage to itself of some kind or other. They all involve intelligent acting of the sensori-motor system, and they are based upon experience. Some time in the past similar external changes have occurred, and the responses made have been successful or not—that is, they have or have not been advantageous. The stimulus is remembered, and also the nature of the responses made, so that when the same external event, or change, recurs the unsuccessful response is avoided and the successful one is made. It does not matter that the master of a ship which is approaching a cyclonic storm may not himself ever have had this experience; he has acquired the experience of others, and knows what response is the advantageous one.

Behaviour, in the sense that we employ the term, is therefore the functioning of the sensori-motor system which is based upon experience. By " experience " we mean individual acquirements, and not something that is inherited. When experience becomes a factor in the determination of the particular response that is being made to a stimulus, something new—that is, something that we have not yet considered—is included in the activities of the animal organism, and our conception of mechanistic responses must be re-examined.

CHAPTER IX

THE MECHANISTIC CONCEPTION OF LIFE

This seems to be the proper place to say something about the "materialistic"—or, as it is now termed, the "mechanistic"—view of the living organism, for, although we have assumed such an hypothesis in all that has been said so far, we are about to abandon it, or, at least, we are about to give to "mechanism" a meaning that is rather different from the one that is usually accepted. Our description of the animal body was first of all mechanical, then we had to make use of physical and chemical ideas, and now we must search for some other concept, which must, nevertheless, still be a logical one.

The body of the higher animal, then, is a system of muscles and other soft parts which are built up round about, or are supported by a system of rigid parts—the skeleton. The latter consists of separate bones immovably attached together, as in the case of the parts of the skull and pelvis, or movably attached, as in the case of the vertebral column and the skeletons of the limbs. In the former cases the skeleton acts as the supports of the soft organs—thus the skull contains the brain and the great sense organs—while in the latter cases the vertebræ and limbs are the apparatus of movement.

Where the bones move on each other they are said to be articulated, and the configurations of the articulations (or joints) determine the ways in which the movements occur. Muscles, ending in tendons, are attached to these movable bones, and by their lengthening or shortening the parts are made to extend or bend on each other. Thus the enormous variety of movements that an animal can carry out depend on the shapes and lengths of the bones, the configurations of the joints, and the modes of attachment of the muscles and tendons.

Further, the muscles are supplied with nutritive matter by a series of conduits—the arteries, capillaries, veins, and lymphatic vessels. At a central point of this vascular system is a propulsive organ, the heart, which keeps the blood and lymph in motion. The directions in which these fluids move are deter-

mined by valves, some of which are placed in the heart itself, others at the place of origin of the great arteries and veins, and others, again, in the veins and lymphatics. The velocity with which they stream through the vessels depends upon the propulsive power of the heart, upon the varying calibre of the arteries and veins, and upon the posture of the body, for it is apparent that more power is expended upon circulating the blood when a man stands erect than when he sits down or reclines.

So far, then, the bodily apparatus is a purely mechanical one—levers of various shapes and "orders," elastic parts that pull these levers, and channels along which fluids are propelled by the action of a force pump and are directed by means of valves. It would be possible to construct a model of the human body which would carry out the same kinds of motions that are made by the living organism. We should have to supply to this model some source of hydraulic power, some automatic contractile vessel worked by a spring that would cause the fluids to circulate in the vessels, and we should have to devise some means of supplying motive force to the muscles—say, compressed air from a reservoir contained somewhere in the body itself. There might be springs here and there on the surface of the model, and these could be made to actuate valves in the reservoir of compressed air, so that by touching them the limbs of the model would perform certain motions. All this is quite possible, and, indeed, automata of such a kind have been constructed. It would, of course, be impossible to imitate the extreme minuteness of some parts of the animal body, or to duplicate the intricacies of the motions of other parts, but such limitations would be due only to our defective craftsmanship. There would, of course, be an essential and very curious difference between the activities of the living animal and those of the mechanical model—a difference which is rather hard to describe in simple language.

The Cartesian Mechanism.—Descartes thought about the animal body as just such a mechanism as that suggested above. The bodies of the lower animals were pure automata, so that if they were touched, or pinched, or otherwise stimulated (as we should say), they would move, or fight, or run away, or cry out, etc., but these responses were as mechanical as would be the movements made by the model when a spring was pressed. The body of a man, he said, was also an automaton, but it contained

a "rational soul," while the bodies of the lower animals did not. The latter could not feel pain or pleasure, and they acted quite unconsciously; but the rational soul in the human body felt the stimulus and response, and could even modify the latter, or could initiate movements of the body by its own volition. Nevertheless, the body of a man or woman was an automaton, and it could do all that the body of a lower animal could do even when the rational soul was inactive.

To understand this conception we must try to forget our modern notions of matter and energy, and we must study Descartes' cosmogony. We shall return to the latter presently, but in the meantime we must consider the physiology that was current before his time and the ways in which he modified it. Now the science of mechanics was very well developed at the beginning of the seventeenth century, and craftsmanship had reached a very high level of attainment. Anatomy had long been studied, so that the general structures of the bodies of man and the lower animals were very well known and had been described in considerable detail. Thus the gross anatomy of the skeleton, muscles, viscera, bloodvessels, brain, and nerves was known to a degree that is not greatly inferior to our knowledge (which excels that of medieval times mainly in its minutiæ). The microscope had not been invented, or at least had not been improved to such an extent as to render it an aid to anatomy, and therefore such organs as the brain, the muscles, nerves, and viscera had then little of the complexity that we now know them to possess. Our modern chemistry did not exist, so that there is hardly what we should call a single chemical idea in all Descartes' physiology. Finally, our kinetic energy was then called *vis viva*, and there was nothing at all comparable with our essentially modern conception of potential energy.

The physiology was, then, largely that of Galen, but it was modified very remarkably by Harvey's demonstration of the circulation of the blood. The materials of the food taken into the stomach were supposed to be converted by the agitation of their particles into *chyle*, a turbid fluid which is present in the small intestine. This was absorbed by the bloodvessels of the gut, and was carried to the liver as the "natural spirits." In the latter organ it became endued with the "vital spirits," and the blood, containing this fluid, ascended to the heart, and was poured into the right auricle. There was a "fire" or "innate

heat" in the heart similar, Descartes says, to that which may be observed in fermenting, damp hay, and this fire was fed by the vital spirits brought to the heart from the liver. As the blood fell into the right ventricle it became expanded, "just as all liquids do when allowed to fall, drop by drop, into a highly heated vessel"—in other words, it was made to boil, but not simply to boil, as we should say, for it yielded nutriment to the fire of the heart at the same time. From the right-hand side of the heart the blood went to the lungs, where it lost some of its vapours, and became thick again by contact with the respired air, "without which process it would be unfit for the nourishment of the fire" of the heart. Returning then to the left ventricle it became distilled, or highly rarefied, with the production of a "very subtle wind, or, rather, a pure and vivid flame," which was the "animal spirits." This was the most agitated part of the blood, and as it ascended into the narrowing arteries leading to the brain the grosser parts were left behind, while the "very subtle wind" or "flame" entered the brain to become stored in the cerebral ventricles.

The more sluggish and thicker parts of the blood, which were nevertheless a hot and nutritive fluid, then became distributed to all the other parts of the body (except the lungs and muscles). Nutrition and the formation of the "humours" (or secretions, as we should say) depended on the existence of sieve-like structures at the extremities of the arteries, so that when the blood was forced through these the larger and more sluggish particles were left behind "in the same way that some sieves are observed to act, which, by being variously perforated, serve to separate different species of grain." The secretions and nutritive parts of the blood were, therefore, filtered off, in the modern sense.

The animal spirits are meanwhile stored in the cavities, or ventricles, of the brain. Now the nerves were described by Descartes as minute tubuli which contained axial threads (our axons). They had a twofold function: on the one hand they transmitted something from the extremities to the brain (our afferent impulses), and on the other they transmitted something (our efferent impulse) from the brain to the extremities. When a sense organ was stimulated, the axial nerve thread was affected in the same way as when a wire is pulled or shaken, and this motion acted upon valves in the walls of the cerebral ventricles, allowing the animal spirits to escape. The latter flowed out-

wards through the tubuli of the nerves, and so into the muscles. Expanding in the latter, they produced the contractions and relaxations which moved the parts of the body.

Now in all this there is nothing but mechanism, in the strict sense. A fluid (the blood) is expanded and rarefied by heat; gross and cold, or slowly moving constituents are separated from finer, more ardent, and more quickly moving constituents merely by the difference of the motions; larger and coarser particles are separated from smaller and finer ones by sieves; liquids flow through tubes, and the thinner parts flow through the narrower tubes more quickly than do the thicker parts; there are valves that are pulled open by stretched organs; there are muscles, which swell or relax according to the way an expansible fluid is thrown into them; these muscles act upon levers, the bones, which thereupon move the limbs and other parts of the body. All this is pure mechanism in our sense.

What were the animal spirits? It is very difficult to avoid reading into Descartes' physiology our present-day notions of energy; still, the spirits were a fluid, but a very rare and subtle one, hot, and thin, and ardent—that is, they were *kinetic* in our sense (like a highly heated gas under pressure). But they could be confined in the thin-walled cerebral ventricles and nerve tubuli, so that their energy must have been repressed in some way—in our term, the energy was potential until it was released by the afferent nervous impulse. As Huxley says, a relatively slight change in Descartes' terminology would have brought his physiology into line with ours.

Obviously he did very much what we do in our chemical and physical hypotheses of living activities—he pushed his speculations to their limits, as the mathematicians would say. His analysis of structure stopped at what could be revealed by dissections, since there was no microscope, and therefore he assumed that his mechanism held true, in the parts that were beyond his observation, just as it did in the parts that he could see. It is very doubtful, however, whether he would have modified his speculations greatly even if he had known as much about the minute structure of the animal body as we do. For instance, the histology of muscle and nerve, as we know it, would lend itself quite well to his mechanical explanation, and the structure of the kidney, as we have sketched it on pp. 71–3, can easily be assumed (in the absence of chemical data, it must be noted)

to be such a mechanical filtering apparatus as he postulated. It is true that he could not see the pores, but neither can we even with the aid of the microscope.

In short, Descartes assumed that his pure mechanism was operative beyond the limits of actual observation (and, as we shall see, that is also assumed by us in respect of our chemical and physical mechanism).

The Influence of Chemical and Physical Investigations.—Now, apart from the influence of chemical discovery, it is not easy to see how the Cartesian physiology need have become modified. But the great advances made by chemistry towards the end of the eighteenth century changed the point of view entirely. The true theory of combustion, as it developed in the hands of Priestley, Black, and Lavoisier, was very revolutionary in its effect on the conception of the nature of vital activity. It was shown that when a piece of metal was strongly heated in the air a calx (that is, an oxide) was formed, and that when carbonaceous material was also made to glow in air some part of the latter disappeared, and "fixed air" (that is, carbonic acid gas) came into existence. Now the animal body, when dried, was found to consist largely of carbonaceous material, and it was discovered that when air was taken into the lungs some part of it disappeared and was replaced by fixed air, just as in the case of the combustion of carbon outside the body. The inference was soon made that in respiration there was an actual process of combustion, and that this occurred in the lungs, or blood, or tissues, and was the source of animal heat. There was not, therefore, an innate heat of the heart, and the latter became regarded solely as the propulsive organ of the circulation. With these discoveries the Galenic physiology became obsolete.

The modern idea of energy came later, and developed naturally from the applications of the motive force of steam that were made by Watt and the engineers, and the theory of the perfect steam engine that was worked out by the French physicist, Carnot. This great man showed that an engine did work by taking heat from a source, and giving it up to a condenser, and that there was a transformation of heat into mechanical energy. His investigation became the foundation of our modern science of thermo-dynamics, which, in its turn, became enormously fruitful in the treatment of chemical problems. Later on Rumford pointed out that mechanical friction generated heat

(a thing that many people before must have observed, but did not think about), and by-and-by Joule estimated how much mechanical work was transformable into just how much heat, and he measured this quantity of heat by noting the increased temperature it could impart to a known mass of water. Joule's work had enormous influence on physiology, for it became possible to estimate the " calorific values " of known quantities of various kinds of food substances. Now a certain mass of combustible material thus became associated with a certain quantity of mechanical work theoretically deducible from it, and so it could be assumed that when food substances were eaten and oxidised in the animal body, some of their heat became transformed into mechanical work. Thus chemical energy could pass into the form of heat, and heat could be transformed into mechanical work. Apparently the animal body was a thermodynamic machine.

Let us note, very shortly, the other great ideas borrowed by physiology from chemical and physical science. Graham, about the middle of the nineteenth century, found that there were two categories of chemical substances—the crystalloids (like common salt) that could pass through the pores of an animal membrane when they were dissolved in water, and the colloids (like gelatine or albumen solutions) which could not pass through. Later on de Vries showed how to measure osmosis—that is, the passage of water through organic membranes. When a vegetable cell is placed in pure water the latter passes through the wall, so that the cell swells up, while, if it is placed in salt solution, which is more concentrated than the sap, it shrinks, because water now passes out from the cell to dilute the stronger salt solution. Graham's research on dialysis and de Vries' work on osmosis have had a profound effect on physiological research—so much so that it has been said that the chemistry of life is largely a matter of the chemistry of colloids. Another most fruitful conception was that of catalysis. It had long been known that fermentations in vegetable and animal substances were due to enzymes (or ferments); that an exceedingly small quantity of the latter substances could produce a chemical change which would not otherwise take place; and that the ferment itself need not be used up during the reaction. But during the nineteenth century it was discovered that a great number of purely mineral substances could act in precisely the same way with other mineral

substances. Thus the same kind of reaction was observed to occur both in organic and inorganic materials, and though we still speak of enzyme action in relation to vital chemistry and catalysis in regard to inorganic reactions, we know very well that the two classes of chemical changes are of the same kind.

Along with all this investigation went on the synthesis of "organic" substances by the chemists. It is almost possible, even now, to feel the thrill that physiologists must have experienced in 1828 when Wohler synthesised urea from mineral substances. Before then there was an apparently hard line drawn between organic and inorganic chemical compounds, and it was thought that there were many substances, such as urea, starch, sugar, albumen, etc., which were only and could only be found in the cells of a living plant or animal. Wohler's synthesis of urea broke through that line, and the far more wonderful syntheses of sugars and polypeptides (the constituents of proteids) by Fischer and his pupils obliterated it altogether. To-day we look forward with complete assurance to the time when starches, proteids, and fats capable of assimilation by the animal body will be prepared, from their elements, by the chemists.

Finally (and now we come down to a relatively short time ago), Jacques Loeb demonstrated the possibility of artificial parthenogenesis, and thus physico-chemical mechanism seemed to be attacking vitalism in the very citadel itself. Before these famous experiments were made parthenogenesis (that is, virgin generation) was known to occur in a very few of the lower animals, but in most lower and all higher forms it was quite unknown; the ovum formed by the female could only be made to develop when it was impregnated, or fertilised, by the spermatozoon formed by the male, and apart from the latter there could, apparently, be no reproduction. Now early in the present century Loeb showed that by simply adding certain chemical substances to the water containing the eggs of sea urchins, the latter could be made to undergo normal development. It is true that the male element in reproduction is not replaced by a chemical substance, for the spermatozoon does much more than simply initiate the process of segmentation and development of the ovum: it adds the paternal characters to the maternal ones. Still, even the initiation of the process of development by a simple mineral salt is a result of the most extraordinary theoretical interest.

So much for the main ideas and methods which have been introduced into biology from the chemical and physical side. Nothing at all has been said here about the impetus which these ideas have given to what we may call utilitarian biology; to processes of further preparation of foodstuffs; to the breeding and rearing of useful organisms; and above all to methods for the prevention and curative treatment of disease. Even now, and much more in the future, the relative freedom from disease that may be enjoyed by every sane man and woman is to be traced back to the investigations made by a few chemists and physicists and biologists and medical men during the last two centuries. To many people all this work is very disagreeable, and they do not like to think about it or even to enquire how it is carried on. Like Tennyson's Princess, they shudder at—

> "Those monstrous males that carve the living hound,
> And cram him with the fragments of the grave,
> Or, in the dark dissolving human heart,
> And holy secrets of this microcosm,
> Dabbling a shameless hand with shameful jest,
> Encarnalise their spirits."

Throughout their lives they live upstairs, so to speak, knowing that most of the things that make living tolerable are the work of those that labour in the kitchen; and one likes to think that some time or other science takes its revenge, and that in the end they have to go down into the basement and found a pathetic reliance on the rather sordid toil that goes on there.

It has been said by Michael Foster, and the statement can easily be verified, that the periods when mechanistic conceptions of life have dominated biology have also been those when the greatest advances in our knowledge of the activities of the organism were made; while the periods during which vitalistic views were generally current were sterile ones from the same point of view.

Modern Mechanisms of Life.—Now one may ask what is the difference between the Cartesian mechanism and that which is represented in, say, the writings of Jacques Loeb, or is there really *any* difference? To Descartes there was nothing in the activities of the animal body but matter, the configurations of matter, and the motions of matter. Everything was mechanical. There is no doubt at all as to what he meant. "I wish it to be considered," he says in the *Discourse on Method*, "that the motion which I have now explained" (that of the circulation of

the blood) "follows as necessarily from the very arrangement of the parts which may be observed in the heart by the eye alone, and from the heat which may be felt with the fingers, and from the nature of the blood as learned from experience, as does the motion of a clock from the power, the situation, and shape of the counterweights and wheels." But to the nineteenth-century biologists there seemed to be no activities in the plant or animal body except those of physical and chemical reactions. What happened in the processes of animal and vegetable metabolism was the result of the chemical constitution of the substances that compose the living organism.

Here we must go back to Descartes' cosmogony. In the extreme generality of his hypotheses, in prophetic anticipation, and in sheer dynamic mentality no one has excelled the great French philosopher. "His imagination," says Clerk Maxwell, himself a man highly gifted with just the same qualities, "knew no bounds." He made not only a cosmogony, but a cosmic evolutionary process. There was nothing, he said, but matter in motion, but matter itself was only extension. Figure and solidity were not essential to a material body, for the latter could be melted or dissolved or broken down without ceasing to be material, and its colour and smell and other qualities that make appeal to our senses were clearly not essential to its materiality. Nothing was essential but the condition that it occupied space. (This anticipates the theory of relativity.) There could be no void, or vacuum, he said, because empty space could only be conceived in terms of matter, which is extension. There could not be action at a distance (here he anticipated Newton), and the whole universe consisted of the same kind of matter (anticipating modern spectroscopic research). The universe was full, and was a continuum (thus anticipating our modern concept of the ether).

Matter originally lay together in closely fitting, angular blocks, but it was set in motion (by God), and so these blocks suffered mutual attrition, grinding each other down and becoming spherical. An exceedingly fine dust or material resulted from this attrition, and this was relatively inert and formed the Cartesian "first element." The rounded particles, which were very small and were in active motion, made the "second element," while there was a "third element" consisting of *particula striata* —that is, particles which had acquired a spiral shape by passing

between the rounded particles of the second element, so that they possessed a rotatory motion as well as a translational one.

The first matter made up the sun and stars—that is, the cosmic bodies that are hot and radiate; the second matter made up the heavens—that is, the atmosphere and cosmic space, which convey radiation; and the third matter was that of the earth and other planets, bodies that are cold and are becoming inert. By vortices in the first and second matters he tried to explain (but with no more success than Kant and Laplace) the evolution of solar systems, while by the motion of the spiral particles he sought to explain attraction. The particles of the second element correspond to our modern atoms (or molecules, as Clerk Maxwell calls them). To what do the fine particles of the first element correspond in our cosmogony?

Fifty years ago we should have said that the universe was made up of atoms, of matter which here and there were aggregated to form stars and planets, comets, nebulæ, and meteoritic dust—in short, cosmic bodies attracting each other with forces depending on their masses and on the distances between them—and that these bodies filled only a most insignificant fraction of empty space. But they attracted each other across this space, and heat and light and electro-magnetic radiation were transmitted through it, so that it could not be empty. There was a medium—the ether of space—and this conveyed the radiation. So much had to be postulated merely to explain things and give us a "working hypothesis," but what was the nature of the ether? It was something that was perfectly elastic, a kind of jelly, so to speak, across which energy could pass without dissipation. It had to be continuous and dense—that is, there could be no interspaces in it such as there are even in the densest kinds of gross matter, which, Sir Oliver Lodge tells us, has a texture like gossamer compared with that of the ether. Now the latter cannot be absolutely continuous and perfectly elastic according to the modern theory of energy as formulated by Planck, for if it were it would possess "infinite degrees of freedom," and thus it would absorb all the energy in a system, leaving none at all to the matter of the system, and that we cannot believe. So quite lately physics has come back again to the notion of a *discrete ether of space*—something which is particulate, but which must nevertheless be continuous in some way or other, how it is difficult indeed to see!

But that would be Descartes' first matter, the exceedingly fine dust resulting from the attrition of the primitive matter which fills up all the interstices between the other molecules. Since the universe was originally quite full, it must have remained full, even when its motions had evolved the three elements. Therefore there is continuity and yet a particular structure, and that seems to be what the Planck theory of energy requires. After many vicissitudes, therefore, physics returns to what seems, in essentials, to be the Cartesian cosmogony.

And, of course, our physico-chemical mechanism reverts to that of Descartes. There is nothing but matter and its configurations and motions, and this is true whether we think about Descartes' matter or the Newtonian matter, or the modern matter of electro-magnetic theory. The Cartesian matter was extension, but what is the matter of to-day? We are gradually accustoming ourselves to think about it as immaterial. Atoms are merely systems of electrons, but electrons are pure energy, and energy, as we have seen, is something about the "nature" of which we do not know anything—all that we know is that it is a measure of causality, and that we can measure it in terms of work done, and that, we have seen, comes in the long-run to measuring a distance or space. So our matter is extension, just as was that of Descartes, and we ought now to call it substance in the philosophic sense of the term.

Anyhow, our mechanism of the organism has come again to a crisis. First of all it was a mechanical explanation of life, and that being insufficient biology resorted to a physico-chemical explanation, which was also insufficient, since physics and chemistry are again becoming mechanical. Looking about for the new conception that biology has now again to borrow from physics, we have little difficulty in finding it, and it would appear as if it were really something new. The concept is given to us in the physical notion of statistical mechanics, and to this we shall return presently.

CHAPTER X

THE MEANING OF PERCEPTION

WHAT we have done so far has been to make a summary of the main results of physiology. Now it is obvious that this summary has been a very bare one, but we have so designed it that the reader should have little difficulty in greatly amplifying his knowledge by the study of a good, recent textbook. Assuming, then, that he has done so, it will be seen that the outcome of both medieval and modern anatomical and physiological research has been to give us an analysis of the means of acting of the animal mechanism—an analysis that has become more and more refined as our chemical and physical methods of investigation have become more powerful and penetrating.

It is quite easy to show this by tracing out the history of physiology with respect to any one particular mode of functioning—for instance, conduction within the nervous system. Thus Descartes made an explanation of action which was based entirely upon anatomical studies, and which, as we have just seen, involved only mechanical ideas. The nerve joining a sense organ—the eye, for example—with the brain contained one kind of fibres, which were, in effect, threads stretched between the receptors and certain valves in the walls of the cerebral ventricles. When these threads were stimulated they were jerked in some kind of way, and this jerk opened the valves and allowed animal spirits to escape from the reservoir in which they were stored. The spirits flowed outwards along nerves which contained another kind of fibres, which were tubes communicating with muscles. When they entered the latter, an expansion in one direction and a shortening in another one occurred, so that the muscle exerted a pull on the movable bone to which it was attached. Clearly we have here the original conception of afferent and efferent nervous impulses. Much later (in 1821) Bell verified this hypothesis in part by direct experiment.. Each spinal nerve contains two kinds of fibres, one carrying impulses to the centre, and others carrying impulses from the centre to the periphery. Further, each spinal nerve has two roots, and

when the dorsal (or posterior) one is severed, there is loss of sensation in some part of the body to which the mixed nerve is distributed. When the ventral (or anterior) root is cut there is, on the other hand, some degree of motor paralysis. Thus there are two kinds of nerve fibres, some carrying impulses inwards and others carrying impulses outwards.

Later on still (in 1852) Waller's researches showed us the anatomical basis for this conception of afferent and efferent impulses. When a nerve fibre is severed from the cell out of which it grows as an axon it dies, and its substance breaks down and degenerates. The cells from which proceed the fibres passing inwards through the dorsal root are in the sense organs, and so inwards from the place of section the nerve fibres degenerate. On the other hand, the fibres passing out in the

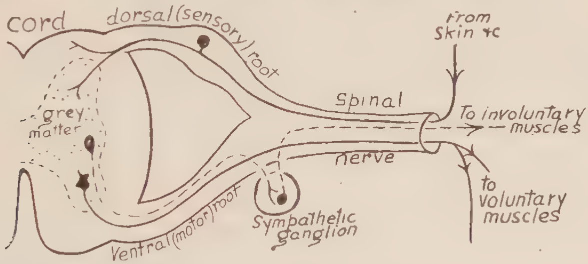

FIG. 46.—DIAGRAM OF THE ROOTS OF A SPINAL NERVE.

A sympathetic ganglion is shown with the two *rami communicantes*, one branch going from the cord into the ganglion, and the other going out from the ganglion to the involuntary muscles (those of the alimentary canal and bloodvessels, in the main).

ventral root proceed from cells in the grey matter of the spinal cord, so that when they are cut through they degenerate on the side of the place of section away from the spinal cord. The result of this discovery was that it became possible to trace the paths in the mixed nerves, in the spinal cord, and in the brain along which impulses travelled, and so the results suggested in Chapters VI. to VIII. were obtained (mainly by experiments on animals). It was also found that many of the fibres in a nerve distributed to a muscle came from the latter—that is, they carried afferent impulses from receptors there. Later, again (almost in our own time), Sherrington's beautiful researches showed that all movements involved antagonistic muscles—that is, when one (flexor) muscle contracted, another (extensor) one relaxed, and this in consequence of one efferent impulse proceeding outwards

from the centre and dividing along two distinct nervous paths as it approached the part that was to be set in action. Finally, while all this was being made out, many investigators had been tracing out the microscopic structure of the receptor organs, nerve fibres, and centres, and also the structure of the muscles, while others were working out the nature of the physical and chemical changes that occur when nerve and muscle become active.

We have still to find out exactly how the physical events that occur outside the body affect the nerve terminations in the sense organs; what is the nature of the nervous impulse itself; what kind of change it produces in the nervous centres; and what are the energy transformations that occur in the muscle when the fibres of the latter shorten or contract. There is no doubt at all that these things will soon become known, and that our analysis of the sensori-motor activity will become much finer than it is. From the point of view of human progress this analysis is all-important, for upon it depends whatever success we shall attain in preventing disease and lengthening life; obviously it is our knowledge of the working of the mechanism that matters from the utilitarian standpoint.

Now the reader cannot fail to see that the results of physiological research are a description of the way in which things that may happen in the animal body do happen, and that the description makes use of the same conceptions that physicists and chemists use; no other results than these could possibly come from an investigation that utilises chemical and physical methods, and so, when we say that science finds nothing in life activities but physico-chemical reactions, we mean that those reactions are all that science looks for, or could possibly attempt to discover. We describe how things happen, but we do not explain why they happen. Of course, it may be said that it is not the business of science to ask why anything happens, but that is just what ordinary people do ask, and it is the task of what we call philosophy to try to answer the question.

Science, then, no matter whether it be physical, chemical, or "natural" science, investigates the ways in which things happen, and it reduces all kinds of events to motions, or, rather, to displacements. What does this mean? the reader will ask. Well, mechanics, in the first place, obviously considers nothing but motions; it deals with material bodies having mass, and with "forces" which "act upon" those bodies. But force is only

the acceleration of a body possessing mass; what we observe is that something that is at rest begins to move, or that something that is moving already moves more quickly or more slowly, and that is what we mean by saying that some force acts on the body. Mass itself is only measured by observing that something would move towards the earth if it were free to do so, and then by preventing it from moving by balancing it against something else—that is, by weighing the body having mass. Flow of heat is only the transference of rapid motions of the molecules of one body to the molecules of another body which are moving less rapidly. Chemical reactions are displacements of the atoms within the molecules of substances; thus, when we add some solution of silver nitrate to solution of common salt a white precipitate is formed thus:

$$AgNO_3+NaCl=AgCl+NaNO_3,$$

the atoms of silver and sodium being mutually displaced with relation to the NO_3 and Cl. Or chemical reactions may be the coming together of atoms to form molecules, as when the gaseous atoms of hydrogen and iodine combine to form hydriodic acid gas:

$$H_2+I_2=2HI.$$

Or they may be the breaking up of molecules into atoms, as when the last reaction is made to reverse itself:

$$2HI=I_2+H_2;$$

or into other molecules, as when the salt, ammonium chloride, dissociates:

$$NH_4Cl=NH_3+HCl,$$

and so on in a very great number of ways. All chemical changes include displacements or rearrangements of atoms, and such changes are accompanied by various physical effects. Heat is generally evolved, or is absorbed, when the rearrangement occurs, and that means that the rapidity with which the molecules of the reacting substances were moving changes. Or the latter may change their state; thus, when petrol is set on fire its molecules, which were previously in the liquid state, react with the oxygen of the atmosphere to form molecules of water and carbonic acid gas, the atoms being rearranged. At the same time the new molecules become gaseous—that is, their freedom and rapidity of motion increase. Or sound may be produced, as when dynamite explodes, and that means that a large quantity

of gas is suddenly produced (the substance of the dynamite now occupying an enormously greater space than it did before the explosion). This sudden production of gas sets up a sound wave in the atmosphere—that is, a series of condensations and rarefactions of the air, which, again, means simply a series of displacements of the molecules of nitrogen and oxygen in the atmosphere. Or, finally, light and other radiant effects may be produced, and these are again displacements of some hypothetical "substance," called the ether of space.

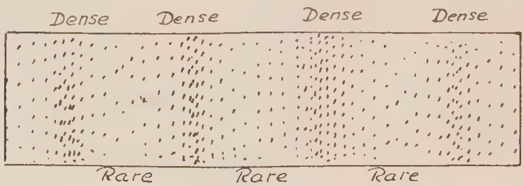

FIG. 47.—DIAGRAM OF A SERIES OF SOUND WAVES IN THE AIR.
The distance apart of the dots represents the condensation and rarefaction of the air.

Thus the older mechanics and the classical chemistry deal with the displacements of bodies or of molecules or atoms—that is, they deal with movements of material substance—while the newer physics and chemistry now deal with radiation which occurs in a medium (the ether) invented to enable us to describe the radiation. Everything now becomes vibratory motions or waves. What is a wave? "If you ask a mathematician," says Sir Oliver Lodge, "what he means by a wave, he will probably reply that the most general wave is such a function of x and y and t as to satisfy the differential equation:

$$\frac{d^2y}{dt^2}=v^2\frac{d^2y}{dx^2},$$

while the simplest wave is:

$$y=a \sin (x-vt),$$

and he might possibly refuse to give you any other answer." He would, no doubt, be sure that you ought to know what a differential equation means, anyhow! Well, all science that is quantitative expresses itself in such statements: the ether *is* really a set of differential equations. When a scientific result reaches such a form it tells us that there are certain *ratios of displacements.* In the above expression the d's are differentials—

that is, differences in measurements of y and x and t that may be as small as we like; y is a measurement of space in a certain (vertical) direction; x is also a measurement of space in a horizontal direction perpendicular to that of y; t is a time measurement, and v is a velocity—that is, it is a ratio, $\frac{s}{t}$. Time, in scientific investigations is always a space measurement; if, for instance, we use a clock, time is the position of the hands relative to their zero position. Thus the equation represents nothing but the ratios of measurements of space; the crest of

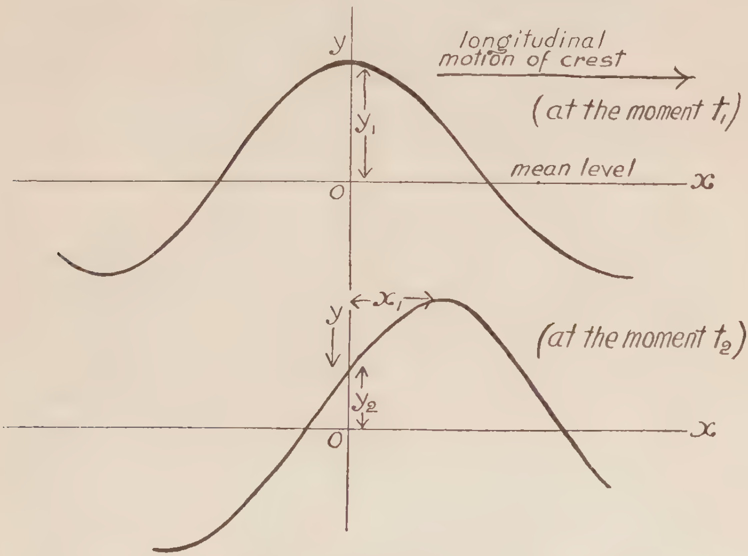

FIG. 48.—DIAGRAM OF A WAVE IN TWO POSITIONS.

the wave, which we may take to be an Atlantic roller travelling uniformly, moves with a certain velocity, v—that is, at a certain moment, t_1, the crest of the wave, which is travelling in the direction ox, is at a certain position ($x=o$), and the water level is at a certain height (y_1). A moment later (t_2) the crest is at a different position, x_1, and the water level, which was originally at the position represented by y_1, has now sunk to the position y_2. Obviously, then, our differential equation tells us *how* the crest of the wave is displaced along the direction ox, while the water level at any position in the line ox is being displaced along the up and down direction oy. It takes a moment of

time, t, at which the crest is at a certain position, and then an "interval" of time, dt, after which the crest has attained a new position, dx. But at the moment t the water level was at the position y, and after the interval dt it has dropped to the new level dy. We call the *d's* "intervals," but it must be noted that they are "infinitesimal" intervals—that is, they may be smaller than any finite lapse of time, no matter how short the latter may be.

Clearly, then, our differential equation simply gives us a series of connected displacements. As time changes—that is, as some standardised mechanism, such as the hands of a clock, are displaced by so much—so the crest of the wave is displaced so much in a horizontal direction, and the water level is displaced so much in a vertical direction. Now all this is not at all irrelevant to the work of this chapter, for our differential equation is a perfect example of a scientific "law."

Science measures motions, or, rather, displacements, and its results must be expressed in measures of space.

Next we turn to the study of organic functioning, and we may choose for an example any bodily activity whatever; in the meantime our treatment of the animal is entirely "objective"—that is, we are regarding it as a system in the physico-chemical sense, something outside ourselves that we can observe and measure just as we can an ocean wave. We might take the action of the heart, or the interchange of oxygen and carbonic acid between the atmosphere and the bloodvessels of the lungs, or the excretion of urea—it does not matter. In all these cases we investigate and express our results as motions, or, more precisely, as measured displacements of something. When we study the circulation we measure the velocity of the blood-stream (that is, the displacement of a blood-corpuscle in an unit interval of time), or the pressure of the blood in an artery (that is, we record the displacement of mercury in a pressure gauge connected with the bloodvessel), and so on. When we investigate respiration we may measure the tension of oxygen in the blood and compare it with the partial pressure of the gas in the air (that is, we observe and measure the volume of a gaseous residue after certain manipulations). When we study the formation and distribution of urea in the blood and kidneys we make quantitative chemical analyses, and in so doing measure the masses of certain substances at certain times and places, and

compare them with the masses of the same substance at other times and places. And in identifying these chemical substances we make use of measurements of space (colour, specific gravity, vapour pressure, boiling-point, chemical properties in general, which are all consequences of the positions of atoms within molecules and of the movements of the atoms and the molecules), and so on. To save time we may assume that the reader is thoroughly conscientious, and desires to verify these statements; he will find that the results of the investigation of animate, no less than inanimate, activities all reduce down to observation of motions and measurement of displacements.

But we shall not, or we shall very rarely, get differential equations like we do when we investigate the ether and electricity and relativity, and so on. We may illustrate this by considering growth. Think of a crystal of salt growing in ideal conditions in a pure solution of sodium chloride: if we know the length of one of its sides we can find its mass, thus:

$$\text{Mass}=c\,(\text{length})^3,$$

and the differential equation is $\frac{dm}{dl}=2cl^2$ (where m=mass, l=length of a side, and c is a constant depending on specific gravity). Knowing the length of one side of the crystal, we can predict its mass.

We cannot do this with a growing animal. If it grew like the crystal does, we could use the equations just given to find the weight of the animal from a measurement of its length. We cannot find this, as experiment will show, and all that we can do is to make an empirical equation after we have measured both length and mass. This equation will be:

$$\text{Mass}=al+bl^2+cl^3+,$$

where l=the length, and some of the constants, a, b, and c, may be negative numbers.

Go on now to a study of behaviour, and the same contrast emerges. Nothing in the way of differential equations is ever possible, and we cannot, in general, predict how a normal animal will respond when we attempt to stimulate it to activity of some kind or other. Yet we can think of a series of organic responses which begin by showing a high degree of determinism and end by failing to show any.

Perhaps we had better define physical determinism, or, rather, illustrate it by an example. A compass needle free to move points in London in a certain direction (about 16 degrees to the west of true north), and it does so because the earth's magnetic force is directed along lines which are running in that direction. Now we know this horizontal component of the earth's magnetism, and we can also find what would be the force exerted by a feeble bar magnet placed at right angles to the magnetic meridian in which the compass needle is situated and (say) a foot away from the pivot of the latter. Then a physicist could calculate the angle through which the needle would deviate when the magnet was placed as we have indicated. This deviation would always be the same provided that the earth's magnetic field and that of the disturbing magnet remained constant. Call the effect of the latter the "stimulus," and the deviation of the needle the "response"; then there is physical determinism, and we can always successfully predict to a high degree of approximation that a certain response will follow the application of the stimulus.

Now take a muscle-nerve preparation (see pp. 134–5) and stimulate the nerve by a feeble electric current; a momentary twitch of the muscle, exerting a certain pull upon a weight attached to it, follows. So long as the muscle remains irritable and unfatigued this response occurs, and we can predict it. There is physical determinism, even although this may not be absolute.

Next take the frog in which the brain has been destroyed, leaving the spinal cord intact. When a drop of acid is placed on its back it will wipe this away with one of its hind-legs, and when other stimuli are applied it will respond in a mechanical, automatic manner. We can, in general, predict what it will do when certain stimuli are applied in certain ways; thus there is determinism. Yet this is not absolute—for instance, the spinal frog appears to prefer to use one leg rather than the other, but if it is prevented from employing that leg it will use the other. Generally the behaviour, in response to stimuli, of the spinal animal is of this mechanical, automatic nature—it can usually be predicted; and this statement is true of frogs, birds, reptiles, and mammals, whatever animals have been the objects of the experiments.

It is also true of a certain number of reflex actions in the normal animal—that is, it is generally true, for reflexes cannot

always be elicited. It is true of habitual, learned, and mechanically repeated actions which have, so to speak, become customary to the animal that makes them. And it is true (again in general) of the instinctive actions which make up a considerable part of the behaviour of invertebrate animals in particular, and even of the higher vertebrates. Yet habits can be varied, and instinctive actions are not quite invariable. Thus some animals, such as bees, which build structures of certain materials, may alter their methods when different materials are supplied to them. Clearly the responses made even by intact, normal animals are not rigidly determined ones capable in all circumstances of being predicted.

And such behaviour as we have indicated in Chapter VIII. in dealing with the functioning of the nervous system shows that there may be spontaneity of behaviour on the part of all animals that have been studied with sufficient care. They react to stimuli sometimes in one way, sometimes in others, and again they may not react at all, or they may act in unpredictable ways even when there are no apparent stimuli. One can see this in men and women: a slight irritation may cause a man to cough again and again, but he may easily repress the response, even when the same physical stimulus recurs. Now in all such cases of variable behaviour to the same kind of stimulus it is open to us to say that there may have been other unrecognised stimuli which modified the response; that in cases where the behaviour seemed to be absolutely spontaneous there "must have been" some causes which we could not trace, or that there were "physiological conditions" introducing elements of uncertainty, and so on. All this may be so; still, the fact is that in a great many cases we cannot say that organic actions are preceded by definite specifiable causes, and when we say that a response "must" always have its appropriate stimulus we simply dogmatise.

It hardly seems necessary to lay stress on the conclusion that we are about to make; nevertheless, it is well to do so. Inanimate occurrences are *always* "more or less" determined, and equivocal results invariably suggest defects in the experimental methods employed, or neglect of some condition or other, or a degree of complexity incapable of complete analysis. That a result can be predicted is a kind of test of a successful physical investigation—in fact, we disregard all other results; they are not useful to us. To some extent this physical determinism is true of the functioning of the lower animals and of the higher ones that

have been subjected to operations which destroy certain parts of the central nervous system. But in most animals there is some indetermination and spontaneity of behaviour, and the more highly organised is the central nervous system, the greater seems to be the degree of indetermination that is exhibited.

The Nature of Sensation.

We are now about to cross over from the "objective" to the "subjective," and the reader is asked to attach no other meanings than those that we specify to the technical terms that we shall employ. By "sensation," then, we mean only the train of physical events which occur when a receptor organ is affected or stimulated by some change in the external medium, and when, in consequence of this stimulation, nervous impulses are propagated along the afferent nerve of the receptor organ into a cerebral or spinal centre. Let us examine this train of events in one case; the reader can easily make similar analyses for others.

The Sensation of Hearing.—A gramophone begins to play—that is, a disc in which there is a spiral groove of uneven depth revolves, raises and lowers a needle, which presses unequally upon a diaphragm and throws the latter into rapid vibrations. These vibrations set up waves of condensation and rarefaction in the air, and the latter impinge on the drum of the ear, setting this into vibrations which resemble those of the diaphragm of the gramophone. The vibratory movements of the tympanic membrane are communicated to the three little bones of the middle ear, which communicate them to a liquid (the perilymph) filling the bony labyrinth of the internal ear. Then the vibratory movements of perilymph are transmitted to the endolymph contained in the membranous labyrinth, and the latter vibrations are communicated to the hair cells or other terminations of the cochlear nerve. Nervous impulses are now set up in the fibres of the nerve of hearing, and these are propagated to the auditory centres of the lower brain.

There is therefore a chain of dependent events: the mechanism of the gramophone, the atmospheric vibrations, the movements of tympanic membrane and auditory ossicles, the vibrations of perilymph, endolymph, and nerve terminations, the nervous impulses, and, finally, the changes produced by the latter in the cells of the auditory centre. Throughout all this series of changes, or motions, there is physical determinism.

Are the changes that occur in the cells of the auditory centre heard? They may or they may not. If a gramophone starts to play in the house next door just as a man is going to bed he will certainly hear it! But a man who is intent on some mental work may not hear a knock at the door, while someone who is with him but is not busy may hear it. And, of course, while he walks through a busy street his eyes and ears receive a multitude of stimuli, and, no doubt, transmit these to his brain, but he is not aware of a large fraction of all this stimulation. Sensation, then, may or may not be accompanied by changes of consciousness. Now there is a stimulus leading to sensation, but there is no "awareness," and, again, when the same stimulus is repeated, we hear or see. Why in one case and not in the other?

There is a "psycho-physical" law which attempts to relate together the intensity of a stimulus that can be measured and the intensity of the feeling of awareness that a sense organ is being stimulated. Let the stimulus be a weight placed on the hand held out straight, and let the subject be asked to say when he feels the increase of weight, as (unknown to him) increments of mass are added to the latter. Say that the weight is P, and let small increments ΔP, $2\Delta P$, $3\Delta P$, etc., be added to P; the subject will not recognise an addition to the weight until this addition has become a certain fraction of the original weight. For instance, he will not recognise that $P+\Delta P$ is greater than P, nor that $P+2\Delta P$ is greater. He *will* recognise that $P+3\Delta P$ is greater than P, though he will *not* recognise that $P+3\Delta P$ is greater than $P+2\Delta P$. Suppose, now, that there is a strict determinism, and that every perception is a function of its stimulus; then it is clear that $f(P)=f(P+\Delta P)=f(P+2\Delta P)$; also $f(P)<f(P+3\Delta P)$; and it also follows that $P=P+\Delta P$, $P+\Delta P=P+2\Delta P$, $P+2\Delta P=P+3\Delta P$, and that $P<P+3\Delta P$; wherefore a thing which is equal to another thing is also less than it! This relation of the intensity of a stimulus to the dependent perception is perhaps the only case in psychology where (after taking some liberties with mathematics) we can make a differential equation:

$$dS=c\,\frac{dP}{f(P)},$$

and clearly we are led to a logical contradiction when we do so.

It is evident, then, (1) that a certain physical stimulus may

give rise to a perception, or it may not do so; and (2) that physical stimuli of different intensities may give rise to the same perception. And therefore, when we attempt to relate our own feelings with the physical stimuli which, we believe, "cause" them, we do not find physical determinism.

Perception.

Here we must explain what we mean by "perception." The term has a very great number of shades of precise meaning in psychology and philosophy, and we cannot attempt to discuss these, or even to choose from them. Quite arbitrarily, then, we mean by perception the *effect in behaviour of the body, or in consciousness, that follows sensation.*

We take the affection of consciousness first in order to clear the way and render our discussion quite simple. The effect of a knock at the door may be *nil* (when we are absorbed in other work and do not hear it), or it may be that we do hear it. The sensation—that is, the train of physical events that we have noted above—is the same in both cases, but in the latter case there is perception: we recognise something outside ourselves. Or in walking along a street we recognise a friend, when there is perception; or we fail to do so if we are "absent-minded." Yet we may be quite sure that an image of the friend was formed on our retinas.

The Objective and the Subjective.—In perception, as thus illustrated, there is a "sensible object"—the man who knocked at the door, *or* the knock at the door, *or* the knocker, or the man whom we recognised in the street. A modern, scientific, realistic philosopher would say that there were certainly sensible objects which stimulated our organs of sense, and there were also "representations," or mental images, of those sensible objects in our consciousness, the sensible, external things which originate physical stimuli being "objective" to us, while the images, or mental representations, were "subjective." A strict idealist (for there are many kinds of idealism) would say that it was quite improper to speak of an external, sensible object, and that all that we could be sure about was the change in our consciousness. Really he ought not to explain anything of the kind to us, for all that he ought to be sure about would be his state of consciousness, we being only affections of that and having no existence except in his mind. No philosopher goes that length, and yet it is the logical outcome of idealism!

Is it not rather absurd to distinguish quite rigidly between the objective and the subjective? Of course, for idealism everything is subjective, but for realism what is the difference, or, rather, where does the objective region merge into the subjective one? What *is* the sensible object, say, in hearing a gramophone play? Is it the nervous change in the auditory region of the cerebral cortex, or the nervous impulse, or the vibrations of the auditory membrane, or the sound waves in the air, or the vibrations of the diaphragm of the gramophone, or the scraping of the needle along the groove in the disc, or the vibrations of the vocal cords of the person who sang the record, or what in a series of stages still further back indefinitely until one gets tired of enumerating them? Nevertheless, common sense recognises something that is, in a kind of way, the object of our recognition—either the gramophone, or the disc, or the singer. Is it a new "record"? Then that is the object. Or a new machine with a different kind of door or shutter that makes it more resonant? That is the object. Or a new song by a well-known vocalist? Then she is the object. Is it not plain from this analysis (which an ingenious reader can make in other cases) that the objective in our perception is that phase of an endless series of phases which interests us, on which we have acted in some kind of way (for we bought the machine, or record), or on which we intend to act (for we may decide to go and hear the vocalist in person)?

"Subjective" and "objective" are therefore attitudes on our part to something which is happening, and they are attitudes that are entirely relative to our interests for the time being. And remember that to speak of "something" which is happening is rather a convenient than a strictly accurate way of speaking. Is there something which moves or vibrates or causes a phenomenon? There may be, said Kant, a *noumenon*, or thing in itself, which moved or vibrated. We do know the movement or vibration, but we cannot possibly know the thing in itself. Why, then, speak about it? But again common sense *does* familiarly speak about things in themselves, and so does experimental science, and for the same reason: it is convenient to do so, and it assists us in our acting and investigating. Just in the same common-sense way we pick out from a long or indefinitely prolonged train of events some one which is more accessible to our action, or which interests us particularly, and we say *that* is the sensible object. To a cerebral physiologist the chemical

changes occurring in the cells of the visual, cortical area might be the sensible object of investigation, while to an optician the crystalline lens of the eye and the muscles of accommodation would be the significant things.

The Kinds of Perception.—The above discussion suggests, then, that a perception is the prolongation into action of some kind, or into virtual, or nascent, or contemplated action, of a sensory process: *it is an actual or potential sensori-motor process.* Now it may be pure (in Bergson's terminology) when it is unaccompanied by the exercise of memory, or it may be mixed when memory is a factor in the prolongation of the sensation into action. We may act in many ways—reflexly, instinctively, automatically, or habitually, as well as deliberately. In reflex actions the unconsciousness of the outer event, or stimulus, that initiates the acting may be complete, and obviously a man may do very difficult (but learned) things without thinking about what he is doing. May we say that automatic or habitual activity is unconscious, or that there is some kind of mental or psychical accompaniment—subconsciousness it may be called—and that this is pure perception? There does not seem to be any reason why we should not say so. A man may do some skilled work in a shop, for instance, filled with the continual noise of machinery, and he may think all the time about something quite different. He may not be conscious (in the usual sense of the word) of the noise of the machines, but he will certainly note the cessation of the latter, or even a change in the rhythm. At any moment, also, during the performance of the "automatic" work on which he is engaged, some slight deviation from the usual course of things may compel the attention to it, so that, although he was not conscious of his own activities in the sense that he deliberated them, some kind of psychical processes certainly was their accompaniment.

When the work is unfamiliar or difficult, or when we act in circumstances that are unusual, then full and vivid consciousness of what we are doing accompanies sensori-motor activity. Thus a skilled musician may play a scale with complete mental detachment from the sensations of musical intervals, but he will attend to the latter with the greatest care if he is playing a composition for the first time. Deliberated and unfamiliar action therefore involves perception that must be distinguished from that which accompanies reflex, instinctive, or habitual sensori-motor activities.

The Problem of Free-Will.

Here we must enquire into the question whether or not volition—that is, the freedom to act or not to act, to act now rather than then, or in this way rather than in some other way—is truly a factor in our behaviour. That we are really free in this respect is a belief held intuitively by most men and women, and it is one upon which codes of morality and systems of punishment and reward are obviously based. Yet it is no less evident to most people that the majority of their actions are not truly free. Inclinations have been formed by imitation and habit, conventions have been established, instinctive tendencies have been transmitted to us by heredity, and material conditions obviously impose restrictions upon our freedom of acting. The consequence is that most of the things that men and women do are the results of "causation" in just the same sense that physical events are caused ones. We are naturally strongly influenced by the methods of science which show us more or less strict determinism everywhere among inorganic things. All that happens there, we see, happens because something else has previously occurred, and will, in turn, lead to the result that something predictable will happen in the future.

Further, the strict sequence of cause and effect that characterises physico-chemical events is, to some extent, based upon a convention. We agree that the law of conservation applies to all real things, and since there are phenomena to which it obviously does not apply (dreams, hallucinations, and spooks), we call the latter unreal. This is quite justifiable, since the laws of energy are the expressions of our ability to act upon things, and spooks are clearly nuisances to us in that we cannot act upon or control them. But is it not clear that the obvious exceptions to determinism are some mental phenomena, and, that being so, is not the logic of applying the law of conservation to mental experience faulty?

However, we adopt Bergson's conclusions here, although we do not summarise his argument. We regard any attempt to disprove the freedom of the will as invalidated by the fallacies to which Bergson draws attention. That leaves us free to accept the natural belief in volition held by most people, and to see in what direction it leads us.

Indetermination in Acting.

If our earlier summary of the modes of organic action is an accurate one—and we think the reader can easily find that it is so by reference to the literature—then it appears that we can make a series of actions, studied " objectively," such that at the beginning of this series there is determination, and at its end indetermination. Tropistic, decerebrate, reflex, instinctive, automatic, and deliberated sensori-motor activities constitute the main terms of this series. Apparently tropisms, the reflexes of spinal animals, and some reflexes of normal animals, are characterised by determinism, while the movements of the higher animals acting normally display what we cannot but regard as spontaneity of behaviour. Of course, it can always be said that the spontaneity is only apparent, that it must be determined, and that we could show this if we knew all the factors. Now, to say that, merely means that we dogmatise.

Reflecting on our own behaviour—that is, approaching the problem from the " subjective " side—we seem to find a similar series of terms. Reflexes, instinctive actions, and habitual actions really make up the majority of the things that we do. Many of these activities are inherited ones; such are all forms of organic functioning, customary modes of locomotion, etc. A great number of other actions have been learned during our individual lifetimes, and are repeated mechanically and without deliberation. Others, again, are conventional in the sense that they are the outcome of obedience to custom and law, or are the responses to what is called " mass suggestion "; thus, most people " instinctively " like to do the things that the crowd does. Now in all such activities true freedom is either wanting altogether or it is only a minimal factor in our behaviour. In organic functioning, reflexes and habitual actions, *we do not think about what we are doing*—that is, consciousness of our activities is absent or it is dim. Perception is what we have called " pure." In the limit, as the mathematicians say, our behaviour approximates to that of the muscle-nerve preparation, or even towards that of the reaction of the compass needle to the bar magnet. In the latter case there is full and strict determinism, and everything that is occurring in the magnet and magnetic field is being prolonged in the reactions of the compass needle.

But in actions that are new to us, in doing things that we are learning, such as playing a scale on a piano, swimming for the

first time, shooting, drilling, or steering a boat, the conditions are, most obviously, different. There is trial and error, and repeated trials with increasing success. There is hesitation, embarrassment, deliberation, and choice. There is full and vivid consciousness of all the conditions; in short, full perceptions of the enviroment, of the results of our action upon it, and memory of past actions that are relevant. While the unfamiliar action is being learned there is indetermination of behaviour, and some true freedom, and what we can only call creative activity. This indetermination, expressing itself as hesitation, deliberation, and choice, *is* our perception; but now it is perception that involves the factor of memory, and which in turn is going to leave behind it both memory and habit.

And so an evolutionary process is essentially a creative one, a notion that need not alarm anyone who thinks about art as creative, as evolving something new. Of course, it can be argued that, just as the evolution of a planetary system from an original nebula is a physical process which is strictly determined, so also must an organic evolutionary process be a determined one. That means that there is nothing new; that if we knew the differential equations that described the state of the nebula we could predict the orbits and masses of the planets and nebula that are to be evolved. Now does this strict physical determinism apply to the process of evolution of species ?

For any evolutionary hypothesis always starts by assuming the existence of variations, and the latter must be shown to be physically determined. But between the simple, muscle-nerve preparation and the behaviour of a higher animal we cannot make any absolute distinction, and variations of form and functioning and habit—that is, the materials, so to speak, on which evolution works—are activities which are essentially the same as muscular responses, tropisms, reflexes, instinctive and habitual and spontaneous actions. And if the proof that the actions of an animal are not really free, but are determined, breaks down (as we believe that it does under Bergson's analysis), how can we maintain that organic variability is physically determined rather than indeterminate, and thus new ? Generally an action is not wholly free, we saw, and generally also a variation is not wholly new. But just as action may generally show some indeterminism, so variations generally show something new. These new things (mutations) are the sources of evolutionary change.

Memory and Habit.

The simplest kinds of organic responses, such as the heliotropic movements of a plant or infusorian or insect larva, or the responses of a muscle-nerve preparation to artificial stimuli, are therefore physically determined, or are nearly so. Reflexes and instinctive actions are also largely determined, but we find that there are often variations from the usual kind of acting. Spontaneous, intelligent, and deliberate actions are very different from the former categories, and we are quite unable to explain them in the way we describe a reflex. What, then, is the difference? Plainly that these higher forms of acting involve *experience;* the response that an animal makes to a stimulus depends not only upon the physical nature of the stimulus, but also upon the effects of former stimuli, and the responses made thereto under analogous conditions to those in which the present stimulus occurs. Instances illustrating this can quite easily be given, but we leave the reader to find them for himself by reflecting upon his own behaviour. A cat, says Mark Twain, which sits down on a hot stove never sits on one again, but neither does she sit down on a cold stove!

What, then, is experience in the physical sense, and how is it stored in an animal? It is stored in two ways: first as motor habits, and next as pure memories.

The whole contents of Chapters VI., VII., and VIII. of this book deal with the mechanism of motor habits; the receptor organ, afferent nerve, intracerebral centres and nervous tracts, efferent nerve and effector organ—such a chain of structures is the unit mechanism that underlies a motor habit. Any skilled technique—say the ability quickly and neatly to deal a pack of cards—involves a preparation, in the course of which such action was practised somewhat laboriously and clumsily. But with repetition experience accumulates—that is, certain afferent nervous impulses become directed easily along certain cerebral tracts, and pass out from the brain into certain definite efferent nerves and muscles, properly timed and co-ordinated, and so produce the required muscular movements. That is to say, definite nervous paths become established or laid down. Every time the same stimuli, in the same conditions, recur, these paths are used the more easily. This is the formation of a motor habit, and all education or training which leads to a technique of any kind establishes such paths and habits.

One must think of the brain of a higher animal as the junction of nervous paths which are extraordinarily numerous. All evolution of the central nervous system increases the number of alternative paths which a stimulus entering the brain may take, so that any receptor organ anywhere in the body, may be regarded as capable of giving rise to a nervous impulse that may enter the brain and become shunted on to the paths leading to any other part of the body. Lay down some "beaten track" in this labyrinth, and we establish a motor habit and so create experience.

And what is common to all automatic activity, whether it be that of a heliotropic insect larva, an instinctively acting bird or mammal, or a trained worker of any kind, is the existence of experience, which is expressed by these ready-made motor mechanisms. But the responses of the heliotropic and instinctive animals are the results of inherited motor habits, whereas the skilled worker has to make them for himself, and he does not transmit them by heredity.

Quite plainly, pure memory is something different from this motor habit experience. The latter is the persistence of the mechanism of receptors, nervous tracts, and muscles that were affected in the formation of an action of some kind, but pure memory we must regard as *the persistence of the perceptions that accompanied the action when it was being learned.* It becomes manifest, apart from the motor habit (which is manifested in action) in pure recollection, in reverie, in dreams, or in the power of visualisation that most people have in some degree. We must think of all the perceptions that we have ever had as continuing to exist somehow, mingled together to form a "multiplicity in unity"—that is, as something which is manifold in its nature, but which is not spread out, as it were, in space. The elements (or constituent notes) of a musical arpeggio are heard, one after another, and so are separate from each other in time; but the same notes, played together perfectly, are heard by a musician and recognised as individual, although they blend to form a manifold or a multiplicity in unity. Memory, then, is something analogous, the fusion, as it were, in one of all our past perceptions.

Where is it, and how is it stored? Undoubtedly it hangs together in some way with the cerebral substance, and the older hypotheses stated that memories were stored away in the cells of the grey matter of the brain, and could be extirpated by the removal of the latter structures. Now, although few biologists

would say as much nowadays, this hypothesis exists in almost as crude a form. " Consciousness," says Jacques Loeb, " is only a metaphysical term for phenomena which are determined by associative memory." " All life phenomena are ultimately due to motions or changes occurring in colloidal substances. The question is, which peculiarities of colloidal substance can make the phenomena of associative memory possible ?"

Now, what do we discover when we investigate the changes in the colloidal substance of the nervous system that follow upon sensation ? Obviously nothing but displacements, as we showed on pp. 167–70. A minute quantity of energy enters the body as the result of the excitation of a receptor organ, and this energy is transmitted along an afferent nerve as an impulse. What becomes of it ?

If the stimulus leads to a reflex, as when we involuntarily contract the pupils of the eyes when we are suddenly exposed to a bright light, then the thing is clear: the energy of the afferent impulse is transmitted (still as a wave of molecular displacements) through the visual and oculo-motor centres, along the oculo-motor nerves, and into the muscles of the iris. There it releases muscular energy, leading to contraction of the pupil. Some of the energy (but a very small percentage) is doubtless dissipated as heat during the nervous passage, just as it would be in an ordinary physical process. There is no conscious perception here, and we can account for all the energy put into the sensation; but what are the circumstances when the stimulation of a receptor organ gives rise to conscious perception, and also leads to some muscular response ? Again, some of the energy passes on to effect the releasing transformation, and again some is dissipated. But an image, or mental representation (the perception), also arises, and can we say that some of the energy transforms into this ? That is to say, does physical energy, which we measure as the displacements of material bodies—as space magnitudes really—transform into consciousness, or perception, which is certainly not the displacement of material bodies, and cannot be measured in terms of space ? No one ventures to say that.

The perception has been called an " epiphenomenon," and has been compared with the luminous trail left by a meteorite which blazes up as it enters the earth's atmosphere; perhaps it is unnecessary to point out the difficulties of this explanation !

For the perception does not fade away when the action has

occurred, as the luminous trail of the meteorite fades when its combustible matter has been consumed. It persists in memory, and it crops out again and again in our consciousness, obtruding itself, as Bergson says, even when we would like to forget it. Something, then, comes into existence as the consequence of sensori-motor activity, and we cannot prove that this is a potential energy stored in the brain, for the latter does not appear to be different when memories coexist with it and when they do not; besides, we can account for all the energy of a sensational process in other ways that are more consonant with scientific methods. And this something continues to exist, and it is utilised (as experience) in future actions, and yet it is not wasted (so, again, it is not energy). And it is real, because it does not fool us (as does a spook), but leads us back to results that are useful and can be verified. What, then, is it, since, apparently, it is not energy?

One can only say that it is memory, or "spirit," as Bergson calls it—the name does not matter so long as we do not associate with it the (necessarily) non-scientific ideas that are connoted by the term "soul." It is something that belongs (as Bertrand Russell says) to the "ultimate furniture of the world"—that is, it is indefinable, just as energy itself cannot be defined in terms of anything else. It may not be a concept peculiar to biology, as we shall try to show later on, but in the meantime we may conveniently regard it as such. Physiology is not concerned with it, and investigates only the chemical and physical processes in which mind or spirit becomes materialised; and psychology, disregarding the concept of energy, starts with that of mind and proceeds with its analysis.

The "Categories of the Understanding."

There are, therefore, both body and mind, or "matter" and "spirit." We shall not argue that this means that there is a dualism, believing with Bergson that matter and spirit are only tendencies that are contrasted in some way or other, or opposite directions, perhaps, of the same series of changes. Assuming, then, the existence of mind as something apart from the organic activities in which it is expressed, we may regard it as legitimate to investigate its working, while disregarding the "link with body." At any rate, it is "up to" science to take that road provisionally and to see to where it leads.

Now quite a considerable fraction of all the "serious" books that have ever been written deal with the question, Have we ideas that exist prior to ordinary experience? We regard this question as having been finally resolved by Kant in the *Critique of Pure Reason,* even if it had not been answered in the affirmative by the methods of science. There are "ideas" or "categories" that are "innate" in the sense that they are in the human mind before the latter attains experience of the outer world. Perhaps it is more correct to say, with Driesch, that they exist and are awakened by experience. Evidently something is there that makes use of or co-ordinates experience, but from the point of view of this book we prefer to think about *modes of mental operation* rather than "innate ideas."

This point of view is actually forced upon us, since we must consider not only the human mind, but also that of the animals other than man. Between the generalised intellect of the highest kind, which was analysed by Kant, and that of the higher animals other than man there exist, even now, almost all possible gradations. Further, the gap between the higher mammals and primitive man has been filled, almost in our own day, by the discovery of extinct human races, and below these forerunners of modern man are the lower mammals, the arthropods and other animals, in which we may easily trace the workings of incipient intelligence. We must assume a series of transitions between man and the lower animals both on the physical and the psychical sides, and we must assume, provisionally at all events, that a "Critique of Comparative Reason" may yet be made, and that until it is made the analysis of the human understanding will always be defective.

A theory of knowledge and a theory of life, says Bergson, are not to be distinguished. What does this mean? We note, first of all, that theory of life and theory of evolution are one and the same thing. No form of life stands apart and is stable, for, obviously, every one—man, the anthropoid apes, the lower mammals, the arthropods—are phases in an evolutionary flux. There must have been continuity at all times in this flux, for evolution has proceeded by little steps, or changes, which are usually so small as to appear insensible to ordinary observation. Every one of these little steps is an adaptation—some change of functioning whereby the organism becomes the more able to *act upon* the outer world. The variation (or, better, *mutation*) may

be some nutritional change, a change of bodily form or colouring rendering the animal less conspicuous to its enemies, a sharpened sensation, an increased power of locomotion, a new bodily weapon such as stronger claws or teeth, a new response to the usual stimuli. It may be one of very many kinds of change, *but it is always something quite new.* Some time or other it occurs for the first time in the evolutionary process, and, having occurred, it becomes a habit.

Reflect upon the discussions of the previous chapters, and it will be seen that we cannot make any clear distinctions anywhere between the "highest" forms of behaviour—that is, the intelligently chosen responses to new situations in which we utilise memory and appear to act spontaneously—and the lowest forms, such as those in which an organism acts tropistically. The freely chosen and spontaneous action may become a motor habit, something incorporated in the "make-up" of the animal that evolved it, but so also does the tropism. Between these extremes, the freely chosen activity that involves the utilisation of memory, reflection, and reasoning, and the very simple tropisms there are all gradations—reflex actions, instincts, automatic and habitual behaviour, etc. Now can we say that the intelligent action occurring for the first time, and thus accompanied by or involving perception, is radically different from the tropism, and that when the latter first occurs as a mutation it also is not accompanied by perception?

Just because of the continuity in organic form and behaviour that evolution shows us we seem obliged to assume that whenever an animal does something quite new there is perception, which has something in common with that which we call perception in ourselves when we do novel actions. The mutation means that the animal enters into a new relationship with the outer world, and just because it does so it becomes aware of some external things in different aspects from those in which they formerly occurred in its experience. Obviously this appreciation of its new relations with the other world is knowledge, which can, therefore, only be attained when there is action that presents novelty. This, then, is what may be understood by Bergson's saying that theory of life is also theory of knowledge.

In the new action there is deliberation and choice, the "turning the situation over in the mind," reflection—in short, the application of pure memory (but not motor-habit memory, for

the activity is to be a new one, and cannot therefore make use of any established cerebral and nervous paths). The memory is applied in a number of ways, and if we may compare mental operations with certain modes of animal acting, we might think about them as beginning by a method of trial and error. The memories of past stimuli and their responses are *tried* in one way or other until a way is discovered that is likely to be successful. The cerebral paths are then discovered or *made*, and the response is effected. The mental operation that was employed and which succeeded is thus an acquired one, and we must suppose that it is transmitted by heredity.

These transmitted mental operations whereby pure memory is utilised in the elaboration of new activities are the Kantian categories.

Apparently, then, we think (that is, employ the categories) because we have acted, or because we are about to do so. That means that we ought to show that all thinking, all intellectual constructions, are actual, or nascent, or virtual ways in which we are acting, or might act upon the outer world. It would not be difficult to show that this is really true, that Newton, for instance, in deducing the law of gravitation, was virtually acting upon the earth-moon system. He could not, of course, move the moon in its orbit with a certain velocity, nor could he pull it towards him, but he could produce accelerations in the velocity of an apple, and he could exert such muscular force as would counteract the acceleration of the latter body when it was free to fall towards the earth. Now, by "producing" this personal power of acting he could imagine himself moving the moon in its orbit, and at the same time pulling it towards the earth in such a way that the observed movements of our satellite were as they would have been if the action had been a real instead of a virtual one. Something like this occurs whenever we think, even in the most abstract way: we do not actually do things, but we "set the points," so to speak, in order that certain actions might occur if it were to become practicable to effect them.

Space and Time.*

There are, said Kant, the categories of quantity, quality, relation, and modality; these are ways in which we think about the objects of sensible experience. There are also the "pure

* See also Appendix II.

intuitions" of space and time. Now it is useful to consider the latter ideas for a moment, for this will enable us to see that the categories have another aspect—they are *mental constraints.* What, then, is abstract space? Space, we may say for the moment, has three dimensions: in whatever way a body may move we can describe its position at any moment by placing it in a "frame of reference." It is distant so much above or below a plane (1) which stretches out horizontally to an indefinite extent; it is also distant so much to the right or left from another plane (2), which is at right angles to the first one, and is also indefinite in extent; and, lastly, it is so much in front or

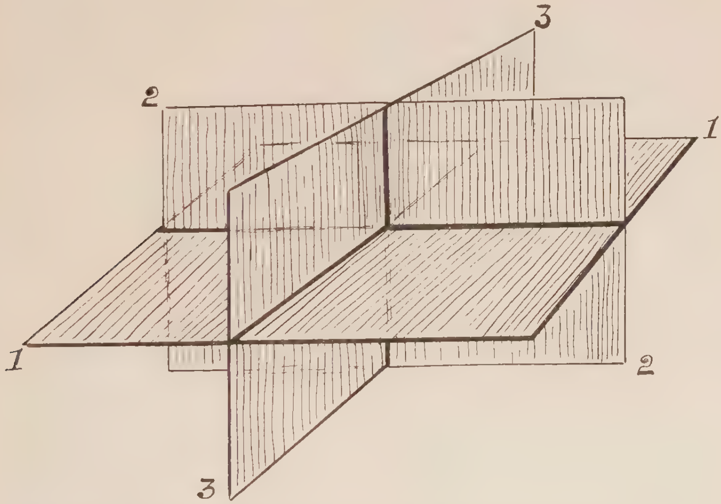

FIG. 49.—THE THREE CO-ORDINATE PLANES OF EUCLIDIAN SPACE.

behind a third plane (3), which is perpendicular to the first two. We suppose, in making this three-dimensional frames of reference, that we are situated at the point where all three planes intersect each other. Plainly, then, if we move we carry the frame of reference with us, and the position of the body we are observing changes relatively to the three co-ordinates.

Thus the motions of all bodies outside our own are relative to our motions. Conceivably we might move in such a way as to keep the frame of reference (which we carry with us) in the same position relatively to a body which would be moving if we were at rest, but which would appear to be at rest relatively to our moving frame of reference. Motions of external objects, then,

can be exactly compensated by the opposite kinds of motions of our own body.*

That means that our three-dimensional space is merely a description of our *three degrees of freedom of mobility.* If we were immovable both in body and eyes, fitted tightly into a solid, transparent universe, we could not have the conception of space, although we could perceive phenomena to succeed each other—there might, for instance, be successive light and darkness. If we imagine ourselves fitted closely into an indefinitely long drain-pipe, we should have freedom of mobility in our dimension (*xox*); if we had to crawl wedged in between two immensely stretched out plates of glass, we should have freedom of mobility in two dimensions (*xox* and *yoy*). If we could move everywhere between the two plates of glass, the latter would be *parallel* to each other; note, however, that we need not think about the drain-pipe being straight, nor of the plates of glass being flat—both might be curved, and still our space would have one or two dimensions. Now remove the plates of glass so that while we are still able to move backwards and forwards, and from side to side, we can also gravitate upwards or downwards.

In the latter case we have three degrees of mobility, and our space becomes three-dimensional (*xox*, *yoy*, and *zoz*). As yet our freedom of mobility is not quite the same in all three dimensions. We can move forwards and backwards and from side to side on smooth ice with equal facility, though we always have the "pure intuition" of backwards and forwards (because we can only see in front), and we always have that of right and left (because the functioning of the nervous system is bilaterally asymmetrical). But we can with difficulty raise ourselves above the level of the ice, and we do not usually fall through it. Therefore the intuition of movement up and down is not nearly so intense as are those of movement in the other dimensions. So, also, we judge distances on the horizontal more accurately than we do in the vertical dimensions, and we are afraid to look down through "empty space" from a height—that is, we have little control of our mobility in that way, and so we are afraid to fall.

And so also non-Euclidean geometries are less familiar and more difficult to us because they express less easily our intuitions of freedom of movement. The four-dimensional geometry is still more difficult, because most people do not appear yet to have

* That is to say, all motions *would be* relative if we did not have the absolute intuition of motion of our own body.

any intuition corresponding with freedom of mobility in a fourth dimension. Clearly in developing four-dimensional geometry mathematicians are trying to remove a mental constraint from their space intuitions.

Our notion of space is not, then, a "form of our sensibility" so much as an intuition, or feeling of our freedom to move in the ways that are possible to us. "Abstract space" is not an absolute something which we contemplate, but it is just the way in which we describe our mobility of body—assuming, of course, that this has become equally well developed in three dimensions.

Neither is time something absolute which we live through. When we speak about it and measure it we do nothing more than observe certain simultaneously occurring events. Last night, when the hands of the clock pointed to twelve midnight, a certain star crossed the meridian, and to-night, after the hour hand of the clock has twice turned through 360°, the same star again crosses the meridian. The time here is a space measurement, but there is something else. We had to live through that space measurement, if one may say so, and our intuition of time past is our mental duration. If we had no memory, all that we should know would be the appearances of the star on the cross wires of the telescope simultaneously with the positions of the hands of the clock indicating twelve midnight. But we remembered the lapse of twenty-four hours because, during that period, our perceptions have endured as memory.

This matter, however, we consider in the following chapter. Meanwhile, we have suggested to the reader an interpretation of the Kantian categories, which seems to be that forced upon us by the study of biology. These mental operations are not "pure conceptions of the understanding," the latter being thought about as something sitting still and apart from the body, so to speak, and contemplating the universe through the sense organs. They are nascent or virtual actions of the body, each of which changes in some way the system which is made up of the body and the universe. In thinking and employing the categories of, say, quantity and substance, we are really acting schematically. Let an analogy make this clear: a man who moves a little lever, and so actuates a hydraulic ram, is not really lifting an enormous weight, nor does a signalman move the trains that pass over a complicated system of junctions. So the categories of the understanding are the ways in which we turn stimuli (the "sensible objects of perception") into the bodily mechanisms that we will to respond.

CHAPTER XI

ON THE NATURE OF LIFE

In our own time, as at the middle of the seventeenth century, speculative biology has come to an impasse. Now, a word more about the Cartesian physiology. Descartes, as we have seen,* made a mechanical theory of the animal body, explaining all the ordinary functioning—that is, the motions of the muscles and fluids and the activities of the glands—by means of the physics known to him. He saw very clearly that there was little difference between the *anatomical structure* of man and that of the other mammals, and so he was compelled to hold that in both cases the animal body was an automatic machine, not essentially different from those that had been constructed by expert mechanicians, but, of course, immensely more complicated. Nevertheless, there were profound differences between the *behaviour* of man and that of the lower animals, and to account for this he supposed that the human body possessed a "sensitive soul" which was not contained in the bodies of other animals.

It would be difficult for a biologist to support this latter assumption in these days, because we are now thoroughly convinced that an evolutionary process has occurred, and that there must, therefore, be absolute continuity between the human and animal minds. We have also studied the psychology and behaviour of the lower animals with a degree of care, and an intuitive understanding, of which we can find no trace in the biology of the Continental schools of the seventeenth century. Further, the study of development shows that precisely the same processes occur during the train of events along which the mature animal body comes from the unfertilised egg, whether we investigate man, or the higher mammal, or the fowl, or the fish. Therefore we cannot now place a "sensitive soul" in the human body and deny its presence in that of the lower animal.

In the seventeenth century, then, there was an absolute distinction between man and the lower animals. The former was dominated or controlled by the soul, which was an immaterial,

* In Chapter IX.

non-energetic agency, and therefore something that was quite outside the scope of physical investigation. This was Cartesian vitalism, an attitude that persisted throughout the greater part of the eighteenth century.

But with the development of modern chemistry and physics biology again applied itself to the investigation of modes of functioning, and, with every new advance made by physical science, our knowledge of the ways in which the animal body worked became more and more intimate. Now it will be clear to the reader, from what we have said in Chapter IX., that all that has been attained by the application of physical and chemical methods has been a great refinement of our analysis of organic activities, and not at all an explanation of animal behaviour. Just the same things may be said about hypotheses of development and evolution. The best known of such—Weismann's theory of the germ plasm—might have become a physico-chemical one, but there is every indication that it has now quite broken down, so that, as yet, we have no explanation of heredity, which involves only the concepts of physics and chemistry. We have, it is true, an analysis which is gradually becoming more minute, but a little reflection will convince the reader that this also is not an explanation.

Within the last generation there has been a recrudescence of vitalism—" neo-vitalism " it is now called, being obviously something that seems to be different from the Cartesian speculations about the sensitive soul. At its best this is seen in the " psychoids " and " entelechies " of Driesch and others, concepts which are applicable to living things only, and not to chemical and physical phenomena. At its worst modern vitalism is exhibited in the crude and even grotesque " spiritualism " which has attained such a vogue with the less resolute thinkers of our own generation. This, then, is the modern impasse to which biology has come. Purely physico-chemical explanations of life are not satisfactory, and the immaterial and non-energetic agencies that are being invoked in their place can have no interest for science, since they cannot be the objects of investigation.

Now it may help the reader in trying to apprehend this situation if he notes that physical science itself is apparently confronted with a somewhat similar impasse. Trace the history of physics during the last two centuries, and it will be seen that its face is being changed all the while. There was the " classical "

mechanics of Newton and his successors; the rise and development of atomic chemistry; the wonderful progress that followed Faraday's discovery of the laws of electrical induction; and then the thermo-dynamic theory elaborated by Carnot, Joule, Rankine, Kelvin, and Gibbs. Then came the electro-magnetic theory of Clerk Maxwell and those who followed him, and, in our own time, the French and English work on radio-activity and the new physics built up by J. J. Thomson, Planck, Einstein, and Nernst. This latter theory, which is still in the making, is obviously the bridge that will lead us across the gulf between matter and the physics of the ether. Apparently, we have yet to find whether or not physical science has said the last word in its effort to explain life.

The Laws of Thermo-dynamics.—Go back now to our discussion of the laws of thermo-dynamics. The first law, we have seen, is really a kind of mental postulate, or convention. We make up our minds that there is *something that is permanent*—that can neither be created nor annihilated—in all the changes that occur in nature. This something we call energy. If it appears to arise out of nothing, or to vanish into nothing, we simply do not believe that apparent result, and we proceed to invent potentialities that will account for the appearances or disappearances. Usually we are successful, and we find that our hypotheses of potential energies work, and we are so led to further discoveries. Then we say that the things we are investigating are real ones, since they are conserved. Or we may find (when we try to investigate spooks) that our hypotheses—astral bodies, higher planes of being, telepathy, and the like—do not work. They mislead us. The test of their validity is that they should enable us to predict, and we find no good evidence that they do so. Therefore, being useless to us, and rather a nuisance, we say that the phenomena of spiritualism are unreal.

That is the first law—that something is conserved so that the total quantity of it in our universe remains constant. It is not so much a physical as an *a priori* " law," or mode of our mentality.

The second law is quite different, inasmuch as there is nothing at all *a priori* about it. It merely describes, in the most comprehensive way possible, our experience of the universe. It tells us how things happen: that water runs downhill; that a red-hot poker taken from the fire cools down to the temperature of the room; that a cigarette burns away, leaving behind it some ash, water vapour, and carbonic acid gas, and evolving heat as it

burns. These things seem to us to be so inevitable that we find it difficult to imagine them happening in the opposite way. It appears to be ridiculous to think of water running uphill of itself; of a table rising up of itself from the floor; of a cold poker becoming red-hot by exposure to the air; or of the ash, the water vapour, and the carbonic acid combining together (with absorption of heat) to form a cigarette. But why should not these things happen? Puzzle over this, and we find we can give no reason other than that no one has seen them happen.

Nevertheless, there is no logical reason why they should not happen, and we can easily imagine them to do so. We can even picture them or imagine ourselves so situated that they appear to happen. Take the case of the red-hot poker: it is red-hot because its molecules are moving so rapidly that their atoms radiate and so give off visible vibrations. While they glow they are vibrating much more quickly than are the molecules of air which come into contact with them, and so they accelerate the velocity of the latter just as a quickly moving billiard ball would accelerate the motion of one that is moving less rapidly when the two collide. There is, therefore, an excess of kinetic energy in the motions of the molecules of the poker compared with that in the molecules of the air in the room, and so the excess becomes levelled down, so to speak. When the poker has cooled to the room temperature all the energy which it contained is still in existence, but it is now uniformly distributed between the metal and the air which came in contact with the latter instead of being concentrated in the poker.

Imagine that we could actually see the molecules and their motions, and that we could photograph them so as to make a kinematographic record. Working the latter, we should then have a picture of the transfer of molecular motions from the hot metal to the cold air, but if we were to work the record backward just the same motions and molecules would be thrown upon the screen, but in the reverse order. We should first see molecules of air and metal moving at certain rates in equilibrium with each other, and we should then see the air molecules begin to move more slowly and to give up some of their kinetic energy to the molecules of the poker, which would move more and more rapidly, until they become red-hot and give off visible radiation. Or imagine a record of a cigarette smoker to be worked backwards; we should then seem to see the smoke and ash solidify to

form the cigarette, and the latter to grow to its original, unlit, unsmoked size. If the molecules were visible, we should see those of the ash, the water, the carbonic acid gas, and the particles of smoke combine together to make up the molecules of the cellulose of the tobacco and paper. We should see energy taken up from the air and become concentrated, so to speak, in the glowing cigarette end, and then pass into the potential, chemical state in the tobacco and paper.

Or, again, take the famous illustrations of Einstein's theory of relativity. A man looking down from a stationary balloon might have seen the explosion of a mine on the Menin Ridge, but suppose that, during the few seconds of that occurrence, the balloon had been moving away from the earth with the velocity of light; then our observer would have seen nothing happen, although someone in a stationary balloon would have seen the earth, stones, smoke, etc., thrown up into the air. Suppose that the observer had witnessed the explosion from his balloon, and that the latter had then immediately started to move away from the earth with a velocity greater than that of light; then he would (assuming he had a telescope powerful enough) have seen the whole train of events proceed backwards. Smoke, stones, dust, and earth would appear to come together from nowhere and coalesce to form the solid ground.

Apparently, then, there is no logical reason why any physical change should not go in either direction. Water runs downhill, but it might run uphill. (Note that we can make it go uphill by forcing it through a closed pipe, but what we are to imagine is it running uphill itself. We can spend energy in forcing it up, and then we find that we have spent more power than can be recovered by allowing the water to run downhill again and work a pump.) We can think of, or imagine, or picture, the water going uphill of itself, and we cannot find any reason why it should not—except that it does not.

In the abstract, therefore, all physical changes are reversible, but it happens that we are living in an universe in which they are irreversible. This is our experience, and we can generalise it in several ways. The most comprehensive way of doing so is to say that in all things that happen a certain mathematical function, called entropy, increases in quantity. What is meant by entropy we shall explain presently. Note, in the meantime, that the necessary condition that any phenomenon or physical change

may happen in our universe is that there must be available energy, and that this must transform into the inavailable form. In other words, energy must be concentrated somewhere, and when a phenomenon occurs it becomes dissipated, or spread out. Having become dissipated or spread out, nothing more can happen, for this energy has lost its capacity for doing work. The second law of thermo-dynamics states that in all natural changes energy becomes dissipated, or entropy increases.

The Condition of the Universe.—Next, we must consider this problem, Is the universe finite or infinite in space and duration? Or we may put the question more clearly. If we were able to travel away from our earth into outer space, like Richter's Dreamer, should we at length enter regions where there were no longer any stars? Or if we could, like Mr. Wells's Time Traveller, go indefinitely far back into duration, should we come to a time when there were no earth and stars? It may seem foolish to suggest these questions, but, as a matter of fact, we can, provisionally at least, answer the first one. There does seem to be a limit to the number of stars in the sky, and it seems that these form a cluster, or galaxy, which is finite. If the numbers of stars were really infinite, certain consequences would be the result. If there were no absorption of light by dark cosmic bodies the night sky would be an uniform blaze of light, and even if there were absorption of light energy would still be infinite in some form or other. Such is not the case, and so we conclude that the stellar universe which radiates energy is a finite one.*

Is its past duration also infinite? We can easily imagine ourselves travelling further and further away from the earth without limit, and passing out at last from the region of stars, or, more generally, of available energy. But we cannot think of a time in the past, however remote, when the universe did not exist, when there was no available energy. For the quantity of available energy in our universe is decreasing, and in the past it must have been greater than it now is. Was there a time, then, when energy came into existence from nothing? That implies creation, and, since we hold to the law of conservation as a mode of our thought, we cannot, therefore, think of a time when the universe began. We conclude, then, that its past duration is infinite.†

* The theory of relativity helps us here. The universe that we see is finite, *but unbounded.* Its form of space is four-dimensional and spherical. See Appendix II.

† See Appendix II.

Now we take the plain result of our experience—that available energy is continually decreasing in quantity (or that the entropy of the universe is increasing). This is the bed-rock fact of our experience: that everything that happens depletes the universe of its store of available energy. "Every energy transformation that occurs leaves an indelible imprint somewhere on the course of events in the universe considered as a whole." There was an original quantity of available energy in our universe, and this is becoming exhausted as entropy increases. Now this quantity being finite, and duration being infinite, it follows that the time must come when there will be no available energy left (entropy having attained its maximum), and so there must occur a complete cessation of all energy transformations, or phenomena.

But if past time is infinite, why has not this physical death of the universe already occurred? No matter how great a lapse of duration is required, we can still imagine this to be possible. Here, then, we have our physical impasse. The second law, solidly based on our experience, says that entropy tends towards a maximum, when universal happening must cease. Past time is without limit, so that, no matter how slowly entropy is being augmented, the maximum ought to be attained. But the universe is still the *locus* of energy transformations, so that entropy has not attained its maximum value.

Obviously the second law cannot be universally true, although it is true of our experience. Somewhere or other, or at some time or other in the universe, it must be reversed or evaded. Now since it is not logically necessary that entropy should always tend towards a maximum value, we must next enquire under what circumstances the second law can reverse itself; under what conditions may water flow uphill of itself, or may heat flow of itself from a region of lower to a region of higher temperature.

The Reversal of the Second Law.—In order that such an investigation may be possible we must choose some simple, mathematically manageable case. Consider, then, the physical condition of a small volume of some gas, say hydrogen, at ordinary temperature and barometric pressure; it consists of an enormous number of molecules which are moving very rapidly, and so incessantly colliding with each other. It would be rather like a swarm of midges in the air provided that the insects flew about in straight lines instead of avoiding each other. In a volume of hydrogen equal to 1 decilitre (that is, a cube of

rather less than 2 inches along each side), there will be $100 \times 2{\cdot}705 \times 10^{19}$ molecules. Each of the latter is moving, but the velocities are variable within certain limits, and their average is about $1{\cdot}65 \times 10^5$ cm. per second. No molecule can move very far without colliding with some other one, and the average free path of a molecule is about 0·00000182 cm. We may regard them as small, spherical bodies of about $2{\cdot}17 \times 10^{-8}$ cm. in diameter. The average velocity of movement depends on the temperature (or, rather, what we call temperature is the variable velocity of the molecules; the higher the latter the higher is the temperature, and *vice versa*).

Evidently the molecules will be moving in every conceivable direction, and so they must collide with each other in all sorts of possible ways. Usually the collisions will take place at some angle to the directions of movement; sometimes a rapidly moving

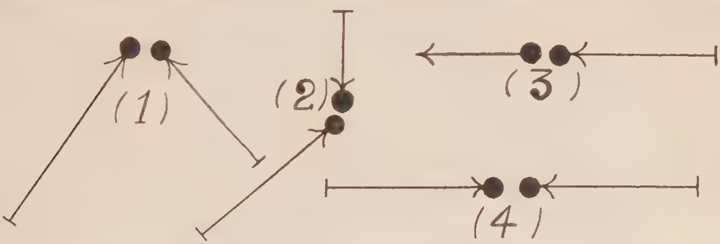

Fig. 50.—Diagram of Chance Collisions between Molecules in a Gas.

molecule will overtake a more slowly moving one travelling in the same direction, and sometimes two, which are moving in the same direction, but towards each other, will collide " end on." Being perfectly elastic bodies, no energy will be dissipated in such collisions. After the collision the directions and velocities will be changed in ways that are easily worked out from the well-known theorems of mechanics. The reader may easily construct these results by making use of vector diagrams, such as those of Fig. 50.

Now by certain mathematical formulæ (deduced by Clerk Maxwell and others from the theorems of probability) the relative frequencies with which encounters between pairs of molecules moving in all possible directions, and with all the possible velocities lying between the upper and lower limits, can be calculated. An encounter in any possible way (such as in the Cases 1 to 4 of Fig. 50) is equally likely to occur. But there

is one case which is of particular interest to us, that of two molecules moving end on with the same velocity (Case 4), and at any moment a certain very small fraction of all the pairs of molecules must collide in such a way. It is possible that all, or $\frac{1}{2}$, or $\frac{1}{4}$, or $\frac{1}{100}$, and so on, of the total number may collide end on, but it is much more probable that $\frac{1}{100}$ will collide end on than will $\frac{1}{4}$, and so on.

It is possible, we say, that all the molecules will at the same moment collide in pairs, and end on, as in Case 4, Fig. 50, and the probability that this sort of encounter may simultaneously occur throughout the whole volume of gas can be calculated. Now, though possible, the chance of this occurrence is almost incredibly small; small as it is, however, we must consider it in speculative reasoning.

Imagine now our decilitre of hydrogen enclosed in a box divided into two equal parts by a partition, and imagine the walls of the box and the partition to be made of some material absolutely impermeable to heat. Let there be a hole in the partition closed by a valve which is also a non-conductor of heat. Let the gas in the right-hand side have a temperature of 20° C., and that on the left-hand side a temperature of 10° C.

In such a case the system contains available energy. There is the same mass of gas in either division, but that on the right has a temperature of 20° C., and so its pressure is higher than the gas in the other division. If the valve is now opened the gas at high pressure will rush through the aperture, and it can do work (say, by turning a small propeller) while the pressure is being equalised. But when the latter condition has been attained the system, in itself, can do no more work. Its total energy is still the same, but there is no difference in intensity, and so no transformation (with regard to pressure change) can occur.*

Consider, also, what happens while the temperatures and pressures are being equalised. The gas in the right-hand division is at a temperature 20° C., and contains a certain quantity of heat, Q'. After the transformation has occurred, the whole mass of gas attains the average temperature 15° C., because Q units of heat have now flowed from a region originally at 20° C. to a region originally at 10° C. Now replace ordinary temperatures by absolute ones—that is, add 273° C. to each of the former;

* For simplicity we neglect here the conditions under which the transformation must occur to render the calculation that follows applicable.

Q units of heat, then, have flowed from a mass at 293° (or 273+20) to another mass at 283° C. (or 273+10). When heat flows from a body at high temperature to another body at low temperature, the entropy of the former is diminished and that of the latter is increased. Change of entropy is measured by the simple expression $\frac{Q}{T}$, Q being the quantity of heat which flows and T being the absolute temperature. The entropy of the gas at 293° is therefore diminished by the amount $\frac{Q}{293}$.

But at the same time a mass of gas, originally at 10° C. (or 283° Abs.) becomes raised in temperature to 15° C. (or 288° Abs.) as the result of Q units of heat entering it, and so we get the change due to the receipt of Q units of heat by the colder gas as $\frac{Q}{288}$. Now the total entropy change due to the Q units of heat lost by the hot gas, and the Q units gained by the cold gas is $-\frac{Q}{293}+\frac{Q}{288}$. Obviously this expression is positive, and so we get our result that *entropy increases* as the result of the mixture of a hot with a cold gas.

Let, then, all this occur in the case of our specified decilitre of hydrogen. The mixture of gases takes place in a few seconds, and the resulting gas, at a temperature of 15° C., is stable and homogeneous as regards temperature. No further work (with regard to its temperature) can be done by it.

But while that is the case, it is still possible that the state of all the molecules in the gas may become such that at a given moment the latter become disposed, purely by "chance," in pairs, the members of which are approaching each other with equal velocity in the same straight line. When they collide their velocities will be the same as before, but the directions in which all the molecules are moving will become simultaneously reversed.

A very important result flows from this. It can be shown (though the proof cannot be given here) that when every molecule completely reverses its direction of motion, the velocity remaining the same, the gas will retrace its past history. That means that the total quantity of gas at a temperature of 15° C. (or 288° Abs.) will separate into two portions—one at a temperature of 10° (or 283° Abs.), and the other at a temperature of 20° C. (or 293° Abs.). Therefore Q units of heat will flow from

a region of 288° to a region at 293°, and entropy will decrease by the amount $\frac{Q}{288}$. At the same time Q units of heat will enter a region at a temperature of 293°, and entropy will increase by the amount $\frac{Q}{293}$. Therefore the total change is $-\frac{Q}{288}+\frac{Q}{293}$, and obviously this expression is negative. Now we get the result that when, by reason of the reversal of the direction of motion of all the molecules of the gas, the latter segregates into regions at different temperatures *entropy decreases.*

We have now obtained a result of considerable interest. It has been shown that it is theoretically possible that a gas originally at an uniform temperature can, of itself, separate into two equal portions, one of which is at a higher temperature than is the other. Heat can flow of itself from a region of lower to a region of higher temperature. A gas which in virtue of its temperature alone possesses no available energy can pass, of itself, into a condition in which it does possess available energy. A system can, of itself, decrease its entropy. All this is very surprising, for these statements mean the same thing that is expressed by saying that water can, of itself, flow uphill!

They mean that we can state the second law of thermodynamics as follows: The entropy of the universe *may* tend to a maximum *or* a minimum.

But we must consider the probability of this reversal of the sign of the second law of thermo-dynamics, for our results merely give a theoretical possibility. The condition that it may occur in such a case as we have investigated above is that at the same moment all the molecules of the gas are arranged in pairs, and the members of each pair are approaching each other end on and with the same velocities. Now this condition is only one of an incredibly great number that may exist in the gas, and the probability that it may exist is the ratio, unity to a very large numerical value. Perhaps the reader will best appreciate what is this probability if we put it in Boltzmann's own way. In order that we may observe this reversal of the second law in a decilitre of gas, we might have to wait for a number of centuries represented by unity followed by 10,000 millions of zeros! It is as probable that it may occur as it is probable that every house in London may catch fire accidentally and independently of all the others on the same day, or that every grown-up person in London

may commit suicide (also independently of all the others) on the same day. Now an insurance company taking risks of houses being burned down by accident, or of people committing suicide, calculates its possible liability from the application of the theorems of probability, and it would safely ignore such risks as those we have just mentioned.

The latter are incredibly small. The chance that a decilitre of gas will separate into two portions of different temperature is also incredibly small, but it is not zero. In the ordinary affairs of life we neglect small risks, and say they are "practically zero," or "infinitesimal," but when we apply such chances in speculations concerning the origin and fate of the universe we must not dismiss them unless we are sure that they are really insignificant in the conditions. Now we are not going to extend Boltzmann's results obtained from a study of the kinetic theory of gases to the whole universe—that is, we must not suppose that a reversal of the second law depends on the collision end on of every molecule. All that we suggest is that it is possible in some way or other that entropy may decrease in our universe instead of increasing. This is a logical possibility, and, given certain arbitrary conditions in a very limited system, it is a probability, the numerical value of which can be estimated. Further, we are compelled to postulate that somewhere or other, or some time or other, the second law of thermo-dynamics must reverse itself—that is, some time or somewhere entropy must decrease, or have decreased, in our universe, otherwise we shall be compelled (as Sir William Thomson was) to postulate a beginning, or creation.

Disentropic Phases in the Universe.—Neglecting, in the meantime, the numerical value of the probability that entropy may decrease (or that unavailable universal energy may become available), we may now proceed to consider the possible history of our universe, taking as our "conceptual model" the changes that occur in a small volume of gas left to itself. In the latter, then, incredibly great periods of time may pass, and during these the molecules of our gas are moving and colliding in a haphazard fashion. Nothing happens in the system considered as a whole; it does no work, although the total quantity of energy contained in it is conserved. But some time or other, if we wait long enough, the system changes, and its original, segregated condition becomes restored. This condition—in which the gas system contains available energy and can do work—lasts for an in-

finitesimal period of time, and the "normal" condition of maximum entropy is again attained.

The visible universe—that is, our galactic system of radiating stars—has, we have reasons for believing, definite boundaries. If we could travel out from our sun in any direction for about 30,000 light years* (that is, $30{,}000 \times 365 \times 24 \times 60 \times 60$ seconds $\times$ 186,000 miles) it is possible that we should reach those boundaries. But beyond this we can still imagine ourselves travelling on indefinitely far.† In this outer space there would, however, be no radiating cosmic bodies, though we might suppose that there are dark, cold suns and satellites, and cold, cosmic dust. Then, after incredibly further voyaging, we might encounter other galactic universes. This means that our picture of the entire universe is one in which the normal condition is physical death—the complete cessation of all happening—entropy having attained its maximum. But here and there in the whole universe, and occupying regions that are of infinitesimal extent, there are individual universes, of which our galactic system is one. The normal condition of the entire scheme of things is that to which we see all physical changes tending, the complete dissipation of energy. But now and then, and for periods of time that are infinitesimal in duration, infinitesimally small regions of the entire universe blaze up, so to speak, the second law becoming reversed and entropy becoming decreased. After this has occurred, the individual universe then much more slowly sinks back again to the normal condition—that in which entropy tends slowly towards its maximum and to which physical death is the limit. The universe, then, in which we are living is an incredibly small fraction of all that exists, and its genesis as an individual, physically active universe was an occurrence essentially similar to that of our gas model. Some time in the past the second law became reversed, and available energy was restored. Then this became slowly dissipated, so that the phase in which we are living is the more probable one—that which tends always towards complete degradation of energy.

In this way we avoid the physical impasse to which we are brought when we assume the universal validity of the first and second laws of thermo-dynamics. Our whole universe becomes a

* A light-year is about six billions of miles.

† Not on the theory of relativity. We cannot go beyond the boundary of the universe, for outside the latter there is no space. See Appendix II.

cyclic order, such that the most probable phases are those in which entropy tends towards its maximum value, and the least probable ones are those in which entropy tends towards its minimum value. As such it is a permanent universe, self-sufficient, without beginning and without end. Throughout its greater extent nothing happens, and this condition we call the normal one. Here and there, however, and for infinitesimally small periods of duration, there is physical activity, and this condition we call the abnormal one. The probability that anywhere and at any time there is such physical activity is of the same order of magnitude as that calculated by Boltzmann for the reversal of direction of motion of all the molecules contained in a small volume of gas.

A Digression on Orders of Magnitude and Duration.—The principal difficulty in appreciating the force of such an argument as the above one lies in the reluctance with which we apprehend extremely small and extremely large magnitudes. We refer all measures, space, and time to those spatial and temporal values that limit our bodily activities, and if something is very great compared with these we are apt to say that it is "infinite," while if it is very small we say that it is "practically zero." Now a magnitude that we can estimate is always finite, no matter how big or how small it may be, and greatness and smallness are always relative to something or other. The same magnitude may be extremely small compared with some other one, but extremely great when compared with yet another. Thus the radius of the earth (4,000 miles) is to us a fairly familiar magnitude, being a distance that we might traverse during a few weeks by means of a steamship. A *micron*, however—that is, $\frac{1}{1000}$ millimetre, the microscopist's unit of length—is a magnitude that is about $1/6378\times10^8$ of the earth's radius, and we may call it an infinitesimal of the first order of smallness.* But, again, a molecule of hydrogen is about $2{\cdot}17\times10^{-8}$ mm. in diameter, so that it is an infinitesimal of the first order when compared with a micron, but of the second order when compared with the radius of the earth.† Starting now with our standard magnitude—that is, the earth's radius—we may compare it with others that are "infinitely great"; thus it is about one-millionth

* It is about $\frac{1}{6}$-billionth part of the earth's radius.

† $2{\cdot}17\times10^{-9}$ mm. $= \dfrac{2{\cdot}17}{10,000,000,000}$ mm., say $\frac{1}{5}$ thousand millionth mm.

of the radius of the orbit of Neptune—that is, the limit of our solar system—and so it is itself an infinitesimal. But the diameter of the solar system is also an infinitesimal when compared with the distance of the nearest fixed star (about $3\frac{1}{4}$ light years, or $3 \cdot 25 \times 6$ billions of miles). Now let the reader calculate for himself this series of magnitudes in terms of the same unit (say a kilometre), and he ought to have little difficulty in seeing that any one, however small or great, may have significance with regard to some other one.

Consider now intervals of time. It is said that an ordinary person can easily realise, or feel, the lapse of duration represented by $\frac{1}{50}$ second of astronomical time, and certainly one second may in some circumstances be a rather prolonged period. Now, $\frac{1}{50}$ second is about $\frac{1}{100000}$-millionth of an ordinary lifetime (that is, it is about 10^{-11} lifetime), and thus, with respect to the lapse of duration which we may call the standard one, $\frac{1}{50}$ second is an infinitesimal of the first order. But in looking at a red light for that length of time we receive some 400 billions of ether vibrations of a certain length—that is to say, 4×10^{14} separate events or things that actually happen. One of these events, therefore, has a duration of 2×10^{-16} seconds, and this we call an infinitesimal of the second order with respect to the lapse of a lifetime.

Probably life itself has existed on the earth for 1,000 million years, so that even a very long lifetime is only about $\frac{1}{10}$-millionth of the whole life-period of the globe. But the latter (10^7 years) must itself be only an infinitesimal fraction of the period of time during which our solar system has been in existence.

The Meaning of Duration.—For men and women this period of $\frac{1}{50}$ second of astronomical time is to be regarded as an unitary lapse of duration: it is the smallest period for which one may exist as a conscious, sentient being. While it passes, a star moves through an arc of about 1·5 seconds—that is, a shift in the sky which can easily be measured by refined astronomical methods. In looking at red light for the same period one gathers up into perception some 400 billions of ether vibrations, each of which has a wave-length of 8×10^{-4} cm. In listening to the note on the piano which is three octaves above the middle C one combines together about forty-one separate vibrations of the atmosphere to make a sound of a certain quality. Our rhythm of duration (in Bergson's phrase) is therefore such that we synthesise these motions, or changes, to make unitary,

individualised perceptions. We see the motion of the star through 1·5 seconds of arc, we see light of a particular colour, and hear sound of a particular pitch. Each of these perceptions is therefore a synthesis of external events effected during the same small fraction of an individual lifetime. Our sensory mechanisms are such that we can make these syntheses, but not some others; thus there are ether vibrations which are less rapid than those corresponding to the red of the spectrum, but we cannot see them, though we can feel them as heat. Below these, again, are others which are much slower, and which we can neither see as light nor feel as heat, though we can detect them by the receiver of a wireless telegraphic apparatus. Above the violet of the spectrum are vibrations which are so rapid that we cannot see them, though we can make them act upon a photographic plate. Other animals are certainly different from what we are in respect of these matters; thus a dog can certainly see light of lower wave-length than we can, and some insects can hear sounds which are too acute for our ears.

The reader will easily see, then, that rhythm of duration varies. Obviously it varies even in ourselves; thus the familiar experience that time passes more quickly when one is fifty years old than when one is ten means that the later ones have fewer events in them—that is, the periods of our duration which correspond with a revolution of the earth round the sun do not gather up so much of other external events when one is old as when one is young. To say that young people have a "fuller" life is not figurative, but is strictly scientific language.

Now think of how the rhythm of duration varies in different animals. It is probable that the imagines (the fully metamorphosed insects) of some species of Ephemeridæ which live for only a few hours can appreciate, or feel as distinct lapses of duration, very much smaller intervals of astronomical time than we do. Suppose, for instance, that a period of $\frac{1}{2500000}$ second can be felt by them (in which period they would still receive some 8,000 millions of vibrations when looking at red light); then their lifetime of a few hours would contain as much (that is, have the same duration) as ours of seventy years. Suppose, again, that some very long-lived animals, such as crocodiles, have unitary periods of duration that are much greater than ours; then their lives would be no longer, for they would contain no more. Note, however, that in such cases the universes constructed from perception would be different ones.

Carry such speculations to their limits. Imagine minds which, just as we synthesise in perception billions of ether vibrations to make visible radiation, might synthesise hundreds of lunar revolutions or solar ones in a single perception. Or in such a mind all the changes that make up the origin, growth, and decay of a solar system might be gathered up as a single perception. As the rhythm of duration thus successively slows down the existence in time (with respect to astronomical, periodic events) would become more and more prolonged, and in the limit it would be without end, or immortal. But note that for such an immortal mind all the details of the universe, and its changes, that exist for us would be unknown, inasmuch as they would be synthesised in other perceptions which can have no meaning for us.

To summarise, then, the very important results that we have now obtained:

If we regard the laws of conservation of energy and augmentation of entropy as of universal validity, we come to an impasse. For the latter law tells us that the changes that occur in the universe tend towards absolute degradation of energy, and therefore towards cessation of all physical phenomena. But since there can be no limit to past time, this ultimate degradation ought to have already occurred, and we know that it has not occurred.

Therefore the second law is not of universal application. We must postulate that it may be reversed, so that, in certain circumstances, energy that has become unavailable may again become available. In other words, we are compelled to think about the universe that we know as a mechanism that has been started, and is now running down. There must be some means of winding it up.

We can imagine no logical reason why unavailable energy should not pass into the available form; all that we can say is that, in our experience, this transformation does not occur. Then, since absolute reliance upon our experience of the universe brings us to an impasse, we must conclude that this experience cannot be inclusive of all that happens.

There must be two directions taken by energy transformations. In one of these energy is continually degraded and entropy becomes augmented. That such changes occur is highly probable —so probable that we know by actual observation of no other direction of change. In the other direction available energy becomes restored, and entropy diminishes. That these changes

occur is highly improbable—so improbable that we have no experience of them, though we can imagine them occurring.

This means that, in addition to the physics that we know, another and a transcendental physics is conceivable.

The Improbability of Life in the Universe.—It follows from what has been said that it is extremely improbable that anywhere in the entire universe energy is available for the production of physical phenomena. It is easy to show that such is the condition that we know, and that even in our individual, galactic universe, where an initial store of energy is exhausting itself, this availability is improbable.

If we were able to travel away from the sun in every direction and with the speed of light, we should reach the boundaries of our solar system in about four hours. Then we should travel outwards into cosmic space for over three years and a quarter before coming to the nearest fixed star. This sphere of space, containing only our solar system (so far as we know), is not, however, empty, but is "full" of ether. The latter is the "substance" of all energetic changes, but we must regard it as inert, or physically inactive. Nothing happens in it of itself. It can be temporarily strained or modified in some way, as when potential energy is locked up in it, or withdrawn from it, or when radiant gravity or gravitational energy is transmitted across it. It is permanently modified in localised regions as physical gravitating matter, which may or may not be the locus of energy transformations. We must think about it as something real, but physically dead or inert. What fraction of this universal substance is, then, physically active?

Calculating the volume of this sphere of three and a half light years in radius, we find that it is about 240×10^{35} cubic miles. In it practically the only cosmic body that contains available energy is our sun, and this has a diameter of (say) 870,000 miles. Finding its volume, we get the value 15×10^{15} cubic miles. It is now easy to find that our sun occupies about $1/2 \times 10^{21}$th of the part of the stellar universe that we have in imagination explored. The probability, then, that we should find physical activity anywhere in the region of space within three and a half light years from our sun is something like 1 in 2,000 trillions.

Now consider the probability that living matter exists in this physically active fraction of the cosmic space which immediately surrounds us. We can hardly think of it as existent in our sun,

nor in most of the planets that surround the latter (unless we extend the definition of life in a way that we do not contemplate just yet). Even upon our own earth living substance forms only a surface film of incredible tenuity when compared with the dimensions of the planet. It is probably most dense in shallow seas near the land, but even there the mass of organised matter is only a few parts per million of water. In oceanic regions, both at the surface and in the depths, the density of life is much less, and on the land (when we take account of polar, mountainous, and desert areas) the density is still less. All that is, of course, only the surface of our planet; in its depths life is very nearly absent.

From the idealistic standpoint life (in strictness, *our own life, or mind*) is all that is, for the universe and all the things that science places there are only mental constructions.

Man, says Pascal, is only a reed, but he is a thinking reed. He is among the least and most fragile of things. But he is also among the greatest of things; he is, indeed, greater than all other things, for he can comprehend the universe.

Life is like Pascal's reed. Anywhere in the universe it is highly improbable that energy exists in such a form as to give rise to physical changes. Even in this fraction of the universe, where there is physical change it is also highly improbable that among these activities there are some that exhibit what we call the phenomena of life. In other words, the chance that life exists anywhere in our universe is an infinitesimal of the second order.

The Physical Nature of Life.—If we would try to explain life we must, first of all, be very clear about what we mean by an "explanation." Consider the motions of the bodies that make up our solar system: the planets revolve round a central sun in elliptical orbits, and the satellites revolve round the planets; the sun, planets, and satellites rotate on their own axes, and the latter precess, or rotate, while still retaining their inclination to the plane of the ecliptic; the ellipticity of each orbit changes periodically; the various bodies "nutate"; each of them perturbs all the others, and so on through a host of motions. To describe all the latter would be very difficult, and the description would be very hard to understand for anyone who is not an astronomer. But assume that each body has a certain mass, that it had a certain initial velocity, and that it attracts every other body with a force that depends on the various masses and on the squares of the distances between the bodies. Then all the motions can

be seen to be consequences of the assumptions that we have just made.

We start with certain very simple concepts, mass and time and space and the law of gravitation, which is a relation between mass and space and time. Given these concepts and a knowledge of the velocities of the various bodies, and we can then deduce all their movements, present, past, and future. Everything that happens in the motions of the solar system happens because the various bodies have mass and attract each other in a certain way. Therefore we " explain " these very complicated movements by the concepts of mass and gravitation. The latter are simple or irreducible—that is, we cannot (so far) explain them by supposing them to be the consequences of something still simpler and more general than mass and gravity.

Knowing the positions of the planetary bodies at any moment, as well as their velocities, knowing also their masses and assuming that the law of gravitation holds good in all circumstances, we can then find what will be their positions at any future time and what were their positions at any past time. These predictions and retrospects generally are successful, and when they fail (as they do in rare instances) astronomers assume other simple concepts (as in the theory of relativity), and then their calculations work out true to what can be observed. Thus we have a planetary theory, which is the explanation of a host of complex events by a very simple hypothesis—that the cosmic bodies have mass and attract each other. This theory is verified, inasmuch as it enables us successfully to predict forwards or backwards.

Now if we had a theory of life we should also have certain very simple, irreducible concepts, and it would be the case that all organic phenomena—growth, reproduction, assimilation, excretion, behaviour, adaptation, evolution, and so on—would be the inevitable consequences of these fundamental concepts, just as solar and lunar eclipses, tides, seasons, etc., are the inevitable consequences of the ways in which the heavenly bodies move, which are, again, the consequences of the law of gravitation. Knowing these fundamental factors, we should be able to " explain " life. We should be able to say what an animal will do at any future time, and what it did at any past time. We ought to be able to trace out the past history of the species to which it belongs, as well as its future evolutionary history, just because we know what the animal now *is* and what are the concepts by means of which we " explain " its activities.

Now we cannot do any of these things. We cannot predict what an individual man or woman will do at any time in the future, though we can sometimes say what a population will do. (The reader must note this distinction between individual and statistical effects; it is most important in speculative reasoning.) We cannot say, merely from a knowledge of its structure and behaviour, what was the past of the species to which an animal belongs, and what is going to be its future. Let there be no misunderstanding here: we do know a great deal about the phylogenies (or lines of descent) of some races of animals, but that is because these evolutionary careers have left historical records. Thus we know (or at least we believe) that the existing one-toed horse has descended from a three-toed species which had, in its turn, come down from a five-toed form, but this is because we have fossil remains of the three- and five-toed horses, because the living animal has vestiges of the second and fourth toes, while the skeleton of the three-toed horse has vestiges of the first and fifth digits. Evolutionary careers have therefore left records in the form of fossil remains and vestigial structures, and we are sometimes successful in reading these and so in tracing out a line of descent. Obviously our success is not due to any process of true deduction from a few fundamental concepts, as is the astronomer's when he calculates backwards to find when eclipses occurred. Eclipses leave no records on the faces of sun, moon, and earth like the evolution of the horse has done.

And so the astronomer can calculate forward or predict, while the biologist cannot do so, since the successes of the latter depend upon records which cannot exist in the cases of events which have not yet happened. Therefore we cannot predict what will be the future evolutionary history of the horse or of any other race of existing animals—or at least no biologist has yet risked his reputation by making such an attempt!

Now we may as well admit that this argument may not appear to possess much force in itself. It may be that biology cannot predict (and so supply the necessary test of the validity of its theories) just because it has not yet attained the necessary knowledge. No doubt Copernicus could not have predicted the times at which equinoctial spring tides would occur at any particular place in the North Sea, for his knowledge of planetary theory was imperfect, and he had not obtained the concept of gravitation. So it may be that biology cannot yet predict just

because its knowledge is incomplete and its concepts are not yet formulated. This latter conclusion is, however, all that we seek to make here—biology, not having attained the concepts that will enable it successfully to predict, has not yet been "explained."

Now let the reader refer back to our discussions of Chapter VIII. It is very clear that organic behaviour (in the cases of the higher animals, at all events) is indeterminate: it cannot be predicted. When anyone says that physical determinism must hold in organic as well as in inorganic functioning, he means that it ought to hold because the concepts by means of which we "explain" life ought to be the same as those by which we explain inorganic happening. It may be that they are the same, and that by-and-by biological predictions will be successful; but the plain fact is that, so far as we know, much of the behaviour of the higher animal is spontaneous, and cannot be predicted, while no satisfactory logical proof can be given of determinism in its application to organic acting.

We are not going to argue here that, because physiological investigation discloses no activities in the animal body other than physical and chemical ones, organic happening is necessarily the same thing as inorganic happening. It is quite true that the physiologist finds nothing in the functioning of an organ but physical and chemical reactions, *for, because of his methods, these are all that he could possibly expect to find.* When he studies the submaxillary gland, say, he finds that a saliva, a liquid of a certain chemical composition, is secreted and poured into the mouth. He finds that this secretion occurs when food has entered the mouth, and when the nerve endings there have been stimulated chemically by the substances of the foodstuff. A reflex occurs and the gland functions. The nature and abundance of the saliva depend on various factors—blood-pressure, osmosis, hydrostatic pressure, chemical reactions in the cells, etc.—and investigation has taught us very much as to the ways in which these various factors act. We have dealt in some detail with this typical example of animal activity in the Appendix, and we may leave the reader to study it further in the textbooks. He will see, however, that all that has been obtained by investigation is a description of the manner of functioning of the gland; there are nervous impulses, changes in the calibre of the bloodvessels, changes in the pressure of the circulating blood, changes in the pressure of the salivary liquid contained in the duct

of the gland, osmotic changes, chemical reactions, and so on. These things do not explain the secretion of saliva: they only describe it. An explanation would place beneath blood-pressure, chemical reactions, etc., some simple irreducible concepts, just as in the planetary theory we place beneath the complex motions of planets and satellites (which correspond logically to the molecular movements occurring in the tissues of the gland) the law of gravitation.

It is, perhaps, not easy for the non-professional reader to appreciate this point. It seems natural to suppose that, because chemical and physical reactions are all that we can study scientifically in the living animal body, these things explain life. They only describe life: *they are the physical expressions of the activities of the organism.* Investigation itself is not primarily speculative, but is rather something useful. Just as the submaxillary gland—and all the other parts of the body that enable it to act—function so as to produce a liquid that digests certain foodstuffs, so the mental mechanism that we call the categories of the understanding functions so as to do something that (like the production of a ferment) is useful to the organism. In the higher races of man it has become speculative also, but even there it is predominantly practical, and (as Bergson shows) is therefore hampered when its aims are purely speculative.

Let the reader reflect on all this, and he will certainly see that physiology has never explained life activities, but has only described them, and that indeed is the glory of the science, for the description has given us (or will yet give us) the mastery over inimical nature. Let him examine the attitude of the "ordinary" man—that is (say), some nine-tenths of all those who are capable by prolonged study of following the methods and results of scientific investigation. This ordinary man will almost certainly ask, What is it for? He will expect that investigation ought to have some useful result, and he will probably be unable to conceal his disappointment (or even contempt) when he learns that the result is only an increase in abstract knowledge!

Life activity therefore expresses itself in physical and chemical phenomena, but physical and chemical reactions do not "explain" life—that is the result to which we seem to be led.

Life and Energy.—In seeking for the explanation we have, therefore, to find some concept which will be special to the phenomena which we call vital ones, and which need not be required when we investigate and explain inorganic happenings.

It must have the " property " of reality—that is, it must not be in contradiction to the law of conservation—for it is to be a means of investigation. Thus we are compelled to reject any of those concepts upon which the theories of spooks are based. It must work—that is, it must lead to the discovery of further workable results or hypotheses—and it must therefore avoid the reproach (addressed originally by Bacon to certain philosophies), and extended to Driesch's " psychoids " by a well-known cytologist, that it is like the vestal virgins, dedicated to God and barren! Now it ought to be clear to the reader at this stage in what direction we are seeking for our concept. We have throughout this book kept the notion of energy in the forefront in order that we might lead up to our thesis that the concept which is special to the organism is one which involves the reversal of the second law of thermo-dynamics. We must not be troubled by the strangeness of such a concept or by the appearance of paradox that goes with it. It is not more strange than some notions in mathematics that have, nevertheless, been fruitful of result—than, for instances, the non-Euclidean postulate that more than one line can be drawn through a point and still be parallel to some other line not going through the point; that the sum of the angles of a triangle may be less than two right angles; that a negative number may have a square root. The test is that, like the notions just given as instances, ours shall have pragmatic value—may work.

So, again, we contrast the inorganic and organic physico-chemical systems.

In the former, anything at all that happens of itself happens because energy transformations take a certain direction. This direction is that which leads to a decrease of the differences of intensity in different parts of the system. Available energy is concentrated in this part of the system rather than that, and if it can be levelled down, so to speak, something will happen. If it cannot be levelled down, being equally distributed everywhere, nothing will happen. If water is accumulated in a reservoir at a higher level than that in a lake, it can flow down into the latter, turn a mill-wheel as it flows, and so produce various phenomena. If it is all contained in the lake, if there is no difference of level, there can be no flow, and no energy available for the production of physical phenomena.

This, then, is the concept by which we " explain " the fact that

physical phenomena do occur; there are in the universe differences of intensity of energy, and these differences tend, of themselves, to become levelled down. As the process of reduction of intensity difference takes place, energy transformations occur and entropy increases. But, as we have seen, the concept of the second law proves inadequate as an explanation in the universal sense, and we are compelled, even in the treatment of inorganic, cosmic systems, to postulate another concept, that of the second law of thermo-dynamics reversed in sign. Somewhere or some time entropy must decrease instead of increasing.

If this reversal were to happen, the results would be unexpected, fantastic, and paradoxical. But a physicist would not be incredulous. He would, probably, seek to be very sure that he was not mistaken, and that his observations were trustworthy; then, having satisfied himself upon these points, he would accept the result. But, as a matter of fact, the reversal does not occur, and every energy transformation that the physicists and chemists can observe and investigate happen because, in this part of the universe known to us, entropy always tends to increase. Therefore the concept which he utilises in order to explain physical happenings is this—energy differences tend, of themselves, to become abolished.

Now it is quite clear that this concept (which is, of course, only another way of stating the second law) does not fully explain organic happening, for in such processes energy differences do not tend, of themselves, to become abolished. Again, we must be very precise in our statement of this result; we do not mean to say that the animal physico-chemical system, or body, does not "obey" the second law. We recall here the caution suggested in the first part of Chapter II., that we must not seek for absolute distinctions anywhere in nature, since these are logical constructions only. There are no such things as mathematical points, straight lines, or planes, for the points and lines and planes which we observe and measure are only approximations. Let a very small spot become smaller and smaller, and "in the limit" it becomes a mathematical point, and so on. Logically, then, we can construct a conceptual world in which there are absolute distinctions between inorganic and organic, and between processes which tend to entropy increase and others which tend to entropy decrease, but *what we do actually observe are only the tendencies which, in reasoning, we carry towards their limits.*

In the activities of life as a whole, what we observe, then, is the tendency for the perpetuation of differences of energy intensity. In purely physical happenings energy tends to become unavailable, but organic changes set themselves against this tendency. When sunlight falls upon desert sand, rocks, raw soil, and upon the surface of the sea, its energy of radiation transforms into heat. Sand and stones become warm, and when the sunlight is withdrawn this heat becomes radiated away into outer space, is dissipated, and is, for us at least, for ever irrecoverable. When it falls on the surface of the sea it heats up the water, which then evaporates, rises up into the atmosphere, is distributed in winds, and is precipitated in rain, etc., returning ultimately to the ocean from which it came. In these changes the motions of the winds and water become transformed by friction into waste heat, which, as before, is radiated away and lost. Sunlight, which is energy of high intensity, thus, of itself, becomes degraded or levelled down, entropy increasing in all the transformations that occur.

Let, however.the sunlight fall upon green vegetation, and something very different occurs. Its energy transforms into chemical changes, as the result of which water and carbonic acid (substances which are fully degraded and have no free or available energy) become combined together, with increase of available energy, to form carbohydrate. Trace the entropy change, and it will be found that this is positive, and has a certain value when solar radiation transforms wholly into waste, low-temperature heat. Trace it again when sunlight is absorbed by the green plant and transforms into the potential chemical energy of carbohydrate, and it will be found that the increase of entropy is now much less than it was. In the first case the solar energy is for ever lost to this world, but in the second it becomes fixed, or stored up, as the chemical energy of wood, vegetation, oil, or coal.

Vegetable life (that is, the predominant form in which life exists on our world), then, has for its tendency the storing up of available chemical energy. The latter becomes locked up, so to speak, in the form of starches, celluloses, proteids, and oils of fruits, seeds, woody tissues, etc. The vegetative processes of reproduction are the most powerful in the animate world, so that on every available place on the surface of the earth, in swamps and in the shallow water of seas and lakes and ponds, plant life spreads and accumulates to the greatest extent possible. Even

when, by reason of overcrowding and the absence of the necessary mineral food substances, this continued multiplication is no longer possible, dead vegetable substance in the form of woody tissues, mould, seeds, leaves, oil, etc., accumulate and form deposits of material of high calorific value. Some of these, in the form of coal, and perhaps oil, remain throughout long periods of geological time in a permanent, utilisable form.

The fraction of the solar energy that is absorbed by green plants, and is afterwards dissipated as waste, irrecoverable heat, is very small. For these organisms are, in general, immobile, and so their energy is not transformed into mechanical work, which would become dissipated by friction into waste, low-temperature heat. But in the animal the latter kinds of energy transformations occur to a far greater extent than they do among the plants. The animal is characteristically a machine for the conversion of potential chemical energy into movement of body and limbs, and this movement inevitably leads to friction, and thus transforms into heat which becomes dissipated. Here we are not considering the processes of reproduction; if we were, we should see that the tendency is, even in the animal kingdom, for the indefinite multiplication of every species, and for the distribution of the individuals over as wide an area of the surface of the earth as possible. All animals, even the most slowly breeding ones, are enormously prolific, and there seems to be no limit to the numbers to which species may theoretically attain. There is, of course, a practical limit which depends upon the quantity of vegetable food substance available, which depends again upon the area of land and sea which can be occupied by green plants, and upon the quantities of the ultimate foodstuffs (chiefly mineral compounds of nitrogen) that are available for the plants.

If there were (say, as the results of volcanic activity) a continued supply of these indispensable food substances (nitrates, nitrites, ammonia compounds, carbonic acid gas, and some other mineral salts), there would seem to be no theoretical reason why the quantity of available energy upon the earth in the form of the organic substance of plants and animals should not steadily accumulate. As it is, some substances which are the results of organic activity do tend to accumulate; these are peat, lignite, coal, perhaps oil, carbonate of lime in the form of coral reefs and other limestone formations, silica in the form of diatom, and radiolarian oozes and deposits, etc. Animal substances (fats,

carbohydrates, and proteids) do not, in general, accumulate, since they are destroyed by bacteria, when they transform chemically into mineral compounds, which again become available as the foodstuffs of plants.

Evidently, then (and the thesis could be supported to a much greater degree than our limits of space allow), the general tendency of life upon the earth is towards the accumulation of available energy in the form of chemical compounds of high calorific value. The process is restricted mainly by animal and bacterial life, and by the paucity on the earth of mineral nitrogenous compounds. But it is clear that on a lifeless planet the enormous store of available energy contained in the incident solar radiation would at once be dissipated, whereas on one which is the seat of life the energy so received tends to be accumulated.

The feral animal, as a rule, disappears and leaves no addition to the earth's store of available energy, except in the somewhat rare cases where its tissues become partially converted into bituminous substances. Of all the myriads of animals that have existed on the earth in past geological times, this remains—here and there some oily or bituminous shales and other rocks, and for the rest "ashes and a skeleton and a name, or not even a name." Throughout their lifetimes the chemical energy taken into the bodies of these animals in the shape of foodstuffs has been, in the main, transformed into mechanical energy, which dissipates into heat that becomes radiated away into space. Some of it goes to form the bodies of new individuals which reach maturity, and then cease to grow, but the fraction which is absorbed in reproductive processes (and therefore adds to the mass of animal life, or accumulated available energy) is much smaller than it is among plant organisms. Two tendencies restrict this accumulation in the animal kingdom: (1) Death and putrefactive decomposition by bacteria; and (2) the greater mobility of animals, which carries with it dissipation of energy. The former, however, do not seem to be inevitable processes, for death is something that might have been averted (and is, indeed, averted in the case of certain protozoa), while conditions in which putrefactive decomposition need not occur are easily conceivable, and may, indeed, be realised.

The tendencies of vegetable metabolism, therefore, make for the accumulation of available energy, but the opposite is the case with animal metabolism. Now this is mainly because the

mechanical energy of almost all animals that now exist on the earth becomes frittered away uselessly in random, misdirected movements which end in friction and dissipation as waste heat. But let these movements be directed and planned, and the energy that would otherwise be degraded tends to accumulate. The tendency to utilise the activities of the animal sensori-motor system in retarding the natural degradation of cosmic energy may easily be traced even in the lower animals, and it operates in the highest degree in human activities.

Even among the lower forms of life we see it, however, in everything that is called an adaptation—that is, in every device which gives an animal greater power over inimical nature. The change of coat colour from brown to white in an arctic mammal as the winter approaches is clearly such an attempt. This is the real meaning of adaptation, and one might discuss it at length if it did not constitute the greater part of biological science.

Obviously, adaptation attains a maximum in the human animal when the latter develops and perfects the use of tools. We do not distinguish between the bodily weapon and the tool or machine adapted or manufactured from inorganic materials: these are, in their effects, as much adaptations as is the change of coat colour from brown to white, or the conversion of a fold of skin into a flying membrane in some squirrels. The ball-bearings in the hub of a bicycle, or the use of grease in the axle-boxes of a railway waggon, are adaptations; they would not exist apart from life; they are the indications of life, and *their effect is to retard the dissipation of mechanical energy into waste heat by minimising friction.* We cannot think of any inorganic, physico-chemical system that does this; the essence of any such system—that is, of any mechanism that "goes" of itself, or of any aggregation of chemical substances that interact with each other—is that the system tends as rapidly as possible towards a condition of equilibrium in which the mechanism ceases to "go," and the chemical substances cease to interact.

Here we get our first concept by which we "explain" physical happening: when water runs downhill; when combustible substances burn and apparently disappear into the air; when coal burns in a fire and generates heat; when proteids and carbohydrates decompose into water, carbonic acid, and mineral nitrogenous salts; when a hot poker becomes cold, and so on—when these things happen, energy becomes degraded or entropy increases, and it is because entropy increases that they do

happen. So water does not run uphill; a piece of brick put into the fire does not generate heat; and water and carbonic acid do not, of themselves, combine to form carbohydrate, because in such processes entropy would necessarily increase. Our inorganic concept is, therefore, **the entropy of the universe tends towards a maximum value.**

On the other hand, things do happen in the course of which energy is not degraded, but, on the contrary, becomes elevated, so to speak. Water and carbonic acid react together and utilise the degrading energy of sunlight, producing carbohydrate. Proteid, carbohydrate, and fat, when aggregated in the form of living protoplasm, do not decompose, but increase in quantity by reproduction. In these energy transformations entropy decreases, and unavailable energy becomes available.* Some adaptations among wild animals clearly tend to reduce the waste of available energy (as when change of coat colour or the accumulation of blubber beneath the skin minimises the loss of heat), and all adaptations have the same general tendency. Human operations may lead to degradation (say by war, by the cutting down of forests, the extinction of seals and whales, or the depletion of coal resources), but they may also have the opposite tendency (as in afforestation, the cultivation of the land, the breeding of domestic animals, the increase of populations, and the invention of antifriction machinery). A man may expend his energy in rolling stones downhill, when he dissipates potential energy in useless friction; or he may by the same expenditure of energy carry stones uphill, so that they are in a position to roll down again, thus accumulating potential energy. In such "vital" processes and tendencies available energy accumulates and entropy decreases.

Therefore the concept by which we explain truly inorganic happening fails to explain organic happening, for in the latter the inorganic concept is reversed.

In living processes the increase of entropy is retarded—this is our "vital" concept.

* The reader must not misunderstand this statement. Starch accumulates in the green leaf exposed to sunlight, but the *whole* system is the green leaf + the CO_2 and OH_2 + the degrading sunlight. In the system thus defined entropy increases very slowly. The system is one in which there are *coupled* energy transformations, (1) the degrading sunlight: and (2) the photo-synthetic process. If there were no coupling, the solar energy would degrade, with a maximum entropy increase; if there is a coupling, the entropy increase becomes minimal. The coupling is always the mark of life activity.

APPENDIX I

A METAPHYSICAL DISCUSSION

THE argument of Chapter X. may be summarised as follows:

"Sensation" is a purely physical process, beginning with the stimulation of a sense organ and ending with the physical affection of a nerve centre. In it are involved only molecular displacements of the substance of nerve fibres and cells. It is not accompanied by changes in consciousness.

"Pure perception" is the prolongation of this physical process of sensation into appropriate actions. Beginning in the animal body with the stimulation of a sensory organ, it ends with a motor action (that is, the co-ordinated movements of a system of muscles), or a glandular change (that is, a process of secretion, or other form of metabolism). It is unaccompanied by any change of consciousness when it is "pure." That is, of course, a limiting case exemplified by typical reflexes, most habitual, visceral responses (respiration, the heart-beat, peristalsis, "mechanical," "habitual," "automatic," and instinctive responses). In such cases consciousness may be absent or very dim.

"Perception" simply means a chosen response—one that is accompanied by some degree of deliberation, and exhibits some degree of freedom or novelty. We are compelled to postulate this indeterminism of response in admitting the continued evolution of form and functioning, and we are convinced of it if we reflect upon our conduct and the motives that sway us. Such deliberated, chosen, and free response is again the limiting case, because habit; physical, legal, and moral restraints; heredity and convention, determine largely what we shall do in any circumstances. But not altogether. There is some degree of true freedom of acting.

The greater the degree of indeterminism that follows upon a sensation, so much greater is the pitch of consciousness. In strong and sustained mental effort there is just this intensely felt deliberation. The latter may end in a choice (when we take some course of action), or it may end in a solution (as when one works out some physical or mathematical problem)—that is, it ends in *an actual or virtual action.* Then one feels the strongest possible mental satisfaction.

Or our mental struggle may be equivocal, so that there is no choice or solution, or at least none that is satisfactory. Then we are certainly impressed with the sense of failure and, it may be, of acute dissatisfaction.

Or, again, there may be persistent sensation that fails to result in appropriate response, and then we experience pain. Between our consciousness that we call mental dissatisfaction resulting from the failure to find a solution and the consciousness that we call "physical" pain there is no clear and essential distinction. But in pain what we describe as "physical" consciousness attains its maximum of intensity, fading away only when, at last, a response (or healing process, or reaction) occurs, or when there is partial or complete destruction of the receptors and neural tracts that are involved in the physical process of sensation.

Life Intuition.—Clearly there is something in the living animal that is additional to, or, at least, is not merely the physical process of, sensation and response. Subject the latter to analysis, and we find a mechanism, receptor organ, afferent nervous tract, central nervous connections and tracts, efferent nervous tract, and effector organ. This may be set in motion, so to speak, and evoke nothing but processes that are certainly energetic ones, although the behaviour that we can thus observe may be appropriate, purposeful, and complete. But it may set in motion again, and then it may evoke response only after deliberation and more or less acute consciousness. Something, then, is operative which is not merely physical sensation and physically actual or virtual response. This may be the exercise of pure memory, the disciplined deliberation that we call reasoning, "mental" and "physical" pain, pleasure, the unsustained and desultory efforts of reverie and "day-dreaming," and so on. It would be as foolish to deny this as to attempt to characterise it all in terms of energy.

Just what to call it we do not know. "Spirit" will be a term that is objectionable to many; mind is only one aspect of the thing that we mean; consciousness is inadequate, for we almost seem compelled to postulate "subconscious" mentality; Bergson's "vital impetus" indicates a passage of some kind or other, and is not just the term we require. In the meantime, at all events, we may refer to it as simply "life intuition," suggesting nothing more than what is meant here in the context. We deal, then, with something that is expressed in the functioning and behaviour of the animal body.

Intuition and the Law of Conservation.—When the animal dies it does not cease to exist, because its molecules fall into new chemical configurations and its energy is conserved even if it is dissipated. But we cannot apply the law of conservation to life intuition, because the law itself is only a mode of operation, or a category, of mind which is the intuition itself. And the application of the law of conservation is necessarily restricted to entities that are measurable, while, obviously, mind and the qualities of mind and "feeling" are not, in themselves, capable of measurement—they are not "in" space and time. It is not a perception that we measure in applying the "psycho-physical" law of Weber and Fechner, but the strength of the stimulus that precedes a change of consciousness, while the mathematical relation between the change of consciousness and the energetic change in the stimulus proves to be a spurious one when submitted to analysis. Intuition is, therefore, non-energetic, non-measurable, *and is not conserved.* All that we know about it *is itself*—it is us. It manifests or expresses itself in animal behaviour and functioning, and so, when the animal body dies—or becomes unable to function—we must believe that life intuition ceases to exist. Or, at the very least, we have no reason for believing that it can survive the dissolution of the body.

Of course, the latter, and therefore the life that it expresses, is immortal in a certain sense. In reproduction a part of the body becomes detached and grows to form a new individual, which again reproduces, and so on indefinitely. Since the ability of expression in functioning and behaviour is thus transmitted through an endless series of generations, something in the life intuition is immortal, but undoubtedly something is abolished in the act of reproduction. This is the intuition of continuous, personal identity, which is lost, or at least does not pass from individual to individual. That which we call memory comes into existence with the individual, and ceases to exist when the latter dies. With memory there is associated, in some way, indetermination of response to sensation, and thus the possibility of evolutionary change. And, of course, with this indetermination goes what we call motive, praise and blame, personal responsibility, and "sin." All these cease with the death of the individual body, some of the activities of which are their expression. If the expression of the whole intuition does not persist, then, can we say that the whole intuition itself is conserved? When we say that life intuition is, but expresses itself in functioning and behaviour, we make the statement because of

our own personal intuition and its expression in our activities, and then we assume that activities in other individual bodies similar to ours are also the expressions of individual life intuitions.

So, in an individual, human career, we seem to see the gradual cessation of intuition: first, the loss of creative mental power at a relatively early period of life; then the slackening of the feelings of initiative and responsibility, and a progressive stagnation of intellect with increasing domination of habit. Then follow the loss of reproductive power and senile decay. What remains of life becomes concentrated in the effort to give bodily metabolism the peculiar "vital" directions, and little by little even that fails and ceases.

What is transmitted in the act of reproduction *is the vital impetus;* in reproduction a life intuition dissociates, one part remaining as the parental body, and the other part becoming the offspring. All the powers of life that manifest themselves in the functioning and actions characteristic of the parental organism are conveyed, in reproduction, to the offspring. What is not conveyed is the memory of the former and, in general, the new form of acting which it acquires in the course of its individual experience. Just as death ends the individuality and personal continuity of the parental organism, so in giving birth to a new individual that personality dissociates itself.

The Working Out of Intuition.—The life intuition of one individual is incommunicable, as such, to another. No process of instruction conveys the knowledge of life in itself; what is conveyed is the materialisation of that life intuition. If there is any way in which feeling and thought can be transmitted from one organism to another otherwise than by an action, we do not know of it. What we are told by modern "spiritualism" as to the possibility of "telepathy" and the like does not come within the purview of science, and, at the very best, those results are grossly materialistic ones, and are their own refutation; it is not "spirit" that the "séances" disclose to us, but matter.

And the individual and personal life intuition is not transmitted from parent to offspring. Heredity is the communication of motor and chemical habit. *Form, the idiosyncrasies of acting, modes of functioning*—these are transmitted. It is the generalised intuition that passes over in reproduction.

In the interpretation of the thoughts and intuitions of other people, and in the interpretation of our own thought and intuition, what we have to do with are the physico-chemical expressions of those thoughts and intuitions. Life manifests itself "objectively" in no other way.

The appearance of the sky at dawn may give one a feeling of strong mental satisfaction. Now to describe that appearance in terms of form, colour, and intensity of illumination, and to explain it by reference to sunlight falling obliquely through an atmosphere laden with water vapour and dust, may seem to many to be an imperfect and sordid interpretation of a very beautiful phenomenon. But that is all that we can do. If we speak of the "dawn in russet mantle clad," do we express our intuition in a manner that is essentially different? Obviously not. In either case the materialism is patent.

The same kind of mental satisfaction may be experienced when we listen to music. If we describe this in terms of rhythm, pitch, and the relations between sounds heard simultaneously and sounds heard consecutively, we may be told that the description is clumsy and inadequate. But the analysts are no more successful. "Thus Fate knocks at the door," said Czerny. "It is the song of the Yellow Hammer," said Beethoven, with reference to the same melodic phrase. Necessarily, the analogy or description, whatever it may be, makes use of materialism.

Sometimes one is seized with a feeling of apprehension, and even quite irrational fear, in walking along a lonely road at midnight. The feeling itself is quite indescribable, and it, like æsthetic ones, is private to the individual that experiences it. But try to describe it: one listens intently; moves as silently as possible; the body is held tensely and in a posture of preparation; heart-beat and respiration respond to the slightest stimuli. Obviously we translate the emotion of fear in materialistic terms.

Our feeling of pleasure on looking at a dawn or sunset, or in listening to music, and the dread that may possess one in a strange situation are certainly experiences *sui generis*. But our intellectual, communicable description of them is, and must be, a materialistic one. "Sunset and evening star" we know to be an atmosphere of a certain constitution penetrated by the radiation from cosmic bodies. The C minor symphony, as we hear it, *is* an exceedingly complex series of displacements of the molecules of the atmosphere. Irrational fear *is* the emotional, afferent reflexes from a body that is thrown into a state of preparation to resist something material. And so on. Seek to understand and express intellectual, emotional, or other intuitive experience, and we find that we can do so only in terms of matter and energy. *Life passes into materialistic phenomena.* Or, at least, that is our "first approximation."

The Description of Nature.—Now we go a step further. Our life intuition, disappearing as such, *inserts* matter and energy into nature. Or, rather, it does not create matter, so much as pass over into it. That is what we should have said twenty years ago, but can we say it now? Obviously not.

For we do not really observe matter and energy in nature. We observe space-time coincidences, and from these we infer space and time measurements. It is not matter, nor even energy, that we infer—it is only space-time measurements or intervals. That is our "second approximation," but we can go further still, thanks to the modern, generalised theory of relativity. That which we know as "nature" is not matter and energy, nor even space and time, but *the relations between space-time coincidences.*

What is the "weather"? Intuitively it is a feeling of discomfort, but we "know" it and describe it, and act upon it (or are acted upon by it, when the "sign" of the action is changed) in strictly materialistic ways: it is rain and wind and a low temperature and mist. Looking into the matter more closely, we find, for instance, that the low barometer is one of the terms in our description, and the quantity of water in the rain gauge is another. But these are space measurements, for the low barometer is a column of mercury (a linear dimension) of a certain magnitude, and the rain-gauge observation is a volume of water (a cubic dimension). The temperature is also a linear dimension—the length of a mercury, capillary column. Coupled with these observations there are time ones: we read barometer, rain gauge, and thermometer at a certain instant when the hands of the clock had moved through a certain arc (since the last twelve noon or midnight). Obviously the time is a space measurement.

So, also, the material water, nitrogen, and oxygen in the environment are time and space measurements. Whatever they feel to us—that is, whatever our intuition of them may be—we describe them as molecules which are made up of atoms which we regard as electrons in movement. And of the electrons we can know nothing but space measurements: a positive nucleus with several electrons and a surrounding swarm of negative ones; relative velocities and stresses, repulsions and attractions. The "actual" molecule, or atom, or electron, moves; thus we have, coupled with positions, instants in time.

That is, our knowledge of nature is space and time measurement, and, indeed, we can see no distinction between the measurement of space and that of time. We do not know space and time intellectually, for space is the intuitive knowledge of our freedom

of mobility, and time is our duration as conscious, remembering individuals. What we know and deal with intellectually are points in space and instants in time. There is nothing between the space points but a mathematical relation and the intuition of a possible actual or virtual bodily movement, and between the time instants there is a similar relation and duration, which is, perhaps, the "stuff" of our intuition.

Proceed a little further, and note that in "reading the barometer" we observe a space-time coincidence. There is an instant at which the top of the mercury column coincides with a mark on the adjoining scale. That instant itself is a coincidence of the hand of the clock with a mark on the scale or dial. There is, therefore, a double space coincidence. In the barometric reading we define a point y_1 in reference to another point $= y_0$, the scale zero. In the time measurement we find an arc by defining a point x, y in reference to the "zero" of the dial—its centre. This latter point we, however, call t, the time. Thus our measurements are defined by reference to some co-ordinate system, and their statement is always an arbitrary or conventional one, and depends on the choice of the scale zeros or co-ordinate systems.

Proceed with such an analysis in relation to any transformation, or event, or object, or phenomenon whatever. The "elements" of our knowledge—the perceptions with which we construct the universe—are space-time coincidences. In any such perception we generally observe the coincidences of four points (three space points and one time instant), x_1, y_1, z_1, t_1, with other four, x_2, y_2, z_2, t_2. Let us state this in a quite dogmatic way (for it can be amply demonstrated, if necessary)—*all the data of our knowledge of nature are space-time coincidences and the relations of such.*

Nature a System of Relations.—We do not deal with even the space and time points, for these have no meaning except with relation to a "frame of reference," or co-ordinate system. The latter is always an arbitrary (though convenient) one, and obviously the position of any point depends on the zero from which it is measured. We take as an illustration (for a clear understanding of the matter is very desirable) the trajectory of a material body falling freely *in vacuo.*

We do not deal with "spaces" and "times" here, but with "differentials," ds and dt. The symbol ds is not an infinitesimally small space, but the *limit* to a space that becomes smaller and smaller without ever becoming zero. It can be so small that the error involved in regarding it as zero will be less than any

standard error, no matter how small this is taken to be. So also with the symbol dt : it is not an infinitesimally small duration, but the limit to a duration which always diminishes. Our falling body, therefore, is *at* certain points—s_0, s_1, s_2, etc.—when the time is t_0, t_1, t_2, etc. The s-points coincide with the t-points, the former being read from a measuring rod, and the latter from a clock. Representing these coincidences graphically, we get the following " one-to-one correspondence " of s-point with t-point.

Obviously we might remove the origins, or zeros, of the time and space scales further to the left without altering the character of the diagram: $t = 1$ second might just as well be $t = 10$, and $s = 100$ feet might as obviously be $t = 1{,}000$—the inclinations of the dotted lines showing the coincidences would not be changed.

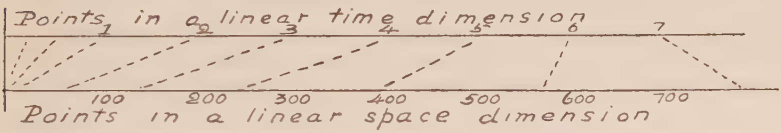

FIG. 51.—THE UPPER POINTS REPRESENT OBSERVED TIMES, THE LOWER ONES THE CORRESPONDING SPACE.

What, then, we obtain from such an analysis is *the relation* between s-points (which have no magnitudes) and t-points (which have no duration). In other words, it is a naked relation that we obtain, and nothing else—there are no space or time regarded as entities. Space and time are not entities, as we have seen already.

The relation is the ratio between the differentials ds and dt; thus—

$$\frac{ds}{dt} = gt,$$

and this is what we find when we observe the fall of a stone *in vacuo*. Such differential equations are the " laws of nature." As a rule, however, we try to avoid using the space-time equations in their differential forms, and we express them, when possible, otherwise. Thus the above relation is more easily recognisable in its integral shape—

$$S = \tfrac{1}{2}gt^2.$$

We have now reached the conclusion to which we have been tending. Nature, as we know it intellectually—that is, the Nature of Science—is a system of relations, and nothing more. It is, however, our practice to speak of these more fundamental relations as " matter," " fields of force," " energy," " atoms," " electrons," " radiation," and so on, all these things " occurring "

in space and time. It would be highly inconvenient in the practical affairs of life to do otherwise, and it would be clumsy even in scientific investigations. Just now, however, we are not concerned with practice, but with the attempt to search into the meaning of things.

These meanings we can grasp in a fumbling kind of way. We postulate *relata* between which we make differential equations or relations. But the relata are only space-time coincidences, *ds*'s and *dt*'s, and these have no " reality " apart from co-ordinate frames to which we refer them, and the choice of such co-ordinate frames is quite arbitrary. Something, however, *is* an absolute element of our knowledge, and this is the relation itself which exists, and is invariant even if the frames of reference vary.

Obviously, then, "our knowledge of nature is a knowledge of form and not of content,"* and what that content is we do not know. We are assuming (though the assumption cannot be proved " scientifically ") that there *is* a content of nature—something apart and independent of the intuition of life. The latter works itself out in *a description of the manner in which it acts upon the content*, but it does not describe the content. That is the ordinary, " natural " way in which we think about things—here is life, in us as well as in a multitude of other animals, and there is an " environment " upon which life acts. That assumption is contained in everything that an animal does, and it is implicit in all our civilisations, and so one cannot but make it a part of our philosophy. We know imperfectly *how* we act upon nature (the environment), but we do not know what it *is* that we act upon. The elements of our scientific knowledge are the forms of the actions, but not the stuff acted upon.

The " Passage of Nature."†—Assuming, then, this nature that exists independently of our form and power of action upon it, we note that it " passes "—that it is a progress or career. It has a tendency in a particular direction, that tendency being described by the second law of energetics. This law we must regard as the fundamental thing in our experience, the concept that is unshaken by any recent development of scientific theory and speculation. And, of course, its fundamental character suggests that the law is in us—in our mode of acting upon nature.

First, we note the phenomena of radio-activity. Certain exceptional substances—the atoms of uranium, radium, actinium,

* Eddington, *Space, Time and Gravitation*, Cambridge University Press. 1920, p. 200.

† A. S. Whitehead, *The Concept of Nature*, Clarendon Press, 1920.

thorium, polonium, etc.—disintegrate, giving off large quantities of radiant energy. We know that this energy is not created in the atom, but is a store that diminishes by reason of its emission. Therefore, the radio-activity of a disintegrating atom comes to an end sooner or later. Uranium passes into radium, and radium, after a long series of intermediate steps, passes into lead. The atomic energy of lead is *bound*, since this substance shows no sign of radio-activity.

Now, the great majority of the chemical atoms are in the same condition as lead, and we know that the few that are still capable of emitting radiant energy *will* pass into the condition of lead, when their energy will exist entirely in the bound state. Extrapolating the process far into the future, we predict the time when all chemical atoms in the earth, sun, and the luminous stars, will have ceased to emit energy—that is, the substance of the cosmic bodies will have passed into the *inert material* stage. So, also, extrapolating the process far back into the past, we may be sure that we pass through stages in which the rate of emission of energy from radio-active elements was progressively greater and greater, and was at a maximum at some remote stage in the evolution of our universe. In that stage the substance of the latter existed in the *pre-material* state. With regard, then, to this generation of available energy by radio-activity, the passage of nature is one from a pre-material to an inert material stage; from the condition of free energy to that of bound energy.

This, doubtless, accounts for the greater fraction, or perhaps all, of the energy that takes part in universal transformations, or physical phenomena. But consider further the free or available energy emitted by radio-active bodies, or free energy in general, apart from any question as to its origin. This energy degrades. Whatever its nature, and whatever the nature of the transformations which it undergoes, it ultimately becomes heat at low temperature. Further, this heat tends always to become equally distributed everywhere throughout the universe, so that the time will come when there will no longer be any difference of intensity, or potential, in the unique form (heat) in which energy will then exist.

That will be the condition of universal physical death ("Warm-Todt," in Clausius' term).

The universe, therefore, tends from a condition of physical activity to one of physical death. It runs down. Free energy becomes completely dissipated, and unbound energy becomes bound. From a condition of minimum entropy the universe

attains a condition of maximum entropy. From a pre-material state it passes into an inert material state.

This is the tendency, or direction, of the passage of nature.

The Relativity of the Passage.—Now one thinks about the life passage in just the same way. If we are right in our interpretation of life intuition as something indescribable (though perfectly well "known" to us) which "runs down" in some way, expressing itself in inert material manifestations, then the life passage exhibits the same tendency, or direction, as does the natural passage.* In Bergson's terminology it *detends.* Note that all recent work interprets "matter," just as Descartes did, as *extension*, and note that the quality of life, mind, memory, intuition (call it what one likes), is that space measurements cannot be made with regard to it. There is, therefore, some quality in life that we express as *intensitiveness*, meaning the opposite of *extension.* By detending this quality becomes something extensive, and so capable of space measurements, and therefore of physical investigation. That which Bergson puts in this way we have tried to put in another way, but the idea involved is the same one.

Life, then, passes always into the inert material state, and the passage is our intellectual description of it.

Assume, now (if for no other reason than to see where the assumption leads), that there is a stuff of nature, an environment of life, something other than life which exists as well as life. Assume that our superficial investigation of nature tells us that this environment does not remain the same, but passes into an inert material state. Life, acting on this stuff of nature, retards the progress of the latter towards the inert material state (when life could no longer utilise it). It retards the augmentation of entropy, but does not (cannot, in fact) prevent the ultimate attainment of maximum entropy. As the temperature of the sun falls life must (as we know it) become the less and less able to persist, and must ultimately cease. That is our ordinary conception of the relation of life to its environment.

But it seems (since one has been compelled to think in another way by the stimulus of the modern relativity theory) that we may just as easily regard nature as something that is at rest, and which does not pass, and hold that the apparent passage is due to the passage of life. If the atmosphere is at rest, and if one

* Remember the (easily ignored) fact, that of *living substance* we literally know nothing. We study the *behaviour* only of a living organism. Whenever we study organic substance, it is necessarily *dead*, inert material that we investigate.

moves quickly through it, one sets up an apparent current of air, and this current may apparently blow in either of two opposite directions, according to the way one moves. It would not be difficult to devise conditions in which it would be impossible for a man to ascertain whether he was at rest and the air were blowing past him, or whether he was being carried through air which was at rest.

So, instead of the environing nature changing as we have suggested, it may be that it is "at rest"; that it is all there, so to speak, though locally different; and that life changes, or moves, so that it encounters the local modifications, just as a man in a railway carriage is carried through a "changing" landscape which is "really" at rest.

There is an apparently formidable difficulty to our thinking anything of the kind: we seem to be convinced that nature passes whether we are there or not. We believe that the sun shone and its energy became degraded before we were born, and that it will shine and dissipate its heat after we are dead. Certainly these processes occur while we are asleep and unconscious (though we are still there in those conditions, it should be noted).

It is worth considering whether we are not there also before we were born, and will be there after we are dead; and to those that accept the doctrine of personal immortality the apparent objection we have suggested ought not, of course, to exist.

Now, we do suggest that we were there, and shall be there, before and after individual life; indeed, that is really the case. We (that is, our life) actually and really existed, in the strictest scientific sense, before our individual lifetime as a fragment of germ plasm in the parental body, and in the grand-parental body before that, and so on indefinitely. And, potentially at least, all the future generations of life are contained in us—in our actual, physical bodies. Therefore, life is continuous, unitary, and always there, just as the hypothetical environment is there simultaneously—that is the plainest and most easily grasped result of biological science.

We ignore it just because we are obsessed by the notion of individual forms, individual bodies, species, genera, families, and so on. But the forms are surely continuous, flowing into and out from each other in an evolutionary process.

And we are also obsessed by the notion of our personal continuous memories, which are most certainly discontinuous careers, begininng with the awakening of the "categories of the

understanding" by experience, and ending with the death of the matured "somatoplasm" (not necessarily the "body," note, for the latter was both somatoplasm and germ plasm). This remembered experience, with the indeterminism that is associated with it, and the morality, immorality, virtue, and "sin" that it is also associated with in virtue of its indeterminism, is discontinuous, comes into existence and ceases to exist. We have no reason to say that it is conserved, and the very notion of conservation is inapplicable to it.

Yet that personality is only a little of life, and the greater fraction of the latter is continuous, and all the life of the world is one. That is just what one means by reproduction and heredity. What one means by evolution (or transformism) is that life changes, that it undergoes passage.

There is, of course, the other difficulty, felt by those who profess "solipsism": there is, literally, nothing in nature but the thinking mind, or rather the thought. That, we hold, is negatived by every life action. It is absurd to "common sense" (and surely no philosophy can disregard that!). It is a pretence in anyone who merely says or writes that he believes it (for in speaking and writing he assumes that there are other minds that listen to his words or read his writings), and we even suggest that there is a kind of intellectual dishonesty in talking about it.

So the objection fails, for life is always and everywhere there (for we cannot say that thought is in space; a man is in a room, but is his mind there? Obviously not when he thinks of the seaside holiday or of his boyhood). Therefore, life being always and everywhere, we are free to suggest that its passage and that of environing nature are relative to each other, and that we cannot say "which is which."

But, again, it seems quite possible to hold that this question of the relativity of the life passage and the environmental nature passage is one that has no meaning. We do not know what is the stuff of nature, since all that we discover by investigation of any kind is a system of naked relations. There may be an homogeneous stuff (as Bergson says), and it may be that the form of this is just what our possibilities of action make it. Atoms, and electrons, and energy, are just the ways, it may be, in which our life intuition cuts up this homogeneous stuff. The latter may be the actual stuff of our consciousness, so that there is, then, nothing in the universe but this: the stuff of life which continually

appears to itself to degrade itself into inert-material—that is, into nothing, for the qualities of inertia are negative ones. Here it is obvious that our discussion is becoming very frankly metaphysical, and must stop.

APPENDIX II

SPACE IN THE MODERN THEORY OF RELATIVITY

Some of the leading ideas in the theory of relativity are not at all difficult to grasp, and they are of extreme importance.

First, then, we note that the Euclidean system of geometry is insufficient for speculation upon the nature of the universe. It is based largely on the parallel postulate—that no more than one straight line can be drawn through a point that lies outside a given straight line and still be parallel to that given straight line. Euclid assumed this, but could not prove it, and no one since him has been more successful. We can assume the contrary—that more than one straight line can be drawn parallel to a given straight line. Then we can prove a number of propositions that seem to be absurd, but are really quite consistent and free from contradiction. The non-Euclidean geometries describe the ordinary things that we see quite satisfactorily, but they are not so easily worked as the classic system, so we use the latter in our everyday affairs.

Second.—The Euclidean geometry of three dimensions does not describe events. A thing is not simply there, so to speak—it always happens. A molecule of water is not really a thing—it is things in motion (electrons). Therefore, we need the idea of time in describing nature. We say that a thing is somewhere—it is so much distant from the plane of X, so much from the plane of Y, and so much from the plane of Z. Its space description involves three variable numbers—X, Y, and Z—but since its description also requires a statement of the time at which it happens, we want a fourth variable, T. (We want the *when* as well as the *where*.)

Thus our universe must, at least, be four-dimensional. Things are really and actually "specified" by four variables: X, Y, Z, T. This is the space-time continuum of Minckowski, adopted by Einstein.

Third.—The four-dimensional (but still Euclidean) geometry is insufficient. The latter is to be thought about as a three-dimensional one of three co-ordinate planes—X, Y, Z—which are

continued somehow in a *straight* line, T. Now this does not describe the universe when we take account of relative positions and motions. Somehow or other the co-ordinates must be *curved*, and to allow for this we have to introduce a fifth dimension. This is "quite all right," and the mathematics of a five-dimensional geometry are as straightforward (though immensely more difficult) as are those of three dimensions. The trouble is that we cannot visualise five dimensions. Still, the mathematical results are there—a fact of very great significance, for an abstract result of this kind always means possible action. Given any abstruse mathematical result, and we may be pretty certain that by-and-by it will mean something "real"—that is, something that practical science, and by-and-by even industry, will do.

So we live in a non-Euclidean universe of four dimensions which is "in" a continuance of a fifth dimension. Leave it at that and see what are the consequences.

The consequences (for our speculations of Chapter XI.) are that space—cosmic space, that is—is "finite but unbounded." Think about this by analogy: the surface of the earth to us is finite, but unbounded. One can go on travelling over it in "straight" lines (geodesics) without being brought up anywhere; there would be no end to our journeying if we could live for ever. We might come back to the same place from which we started, though we should be travelling in a "straight" line, but even then we could still go on *in the same direction.*

Now extend that to cosmic space, and suppose that it, too, is finite and unbounded. We are stepping out of non-Euclidean, two-dimensional, *curved* space into non-Euclidean, four-dimensional, *curved* space. This means that the universe is finite but unbounded. We can go on through it with the velocity of light for ever, and always in the same direction. There is no end to our journey. Perhaps we might come back to the starting-place, perhaps not; if we did, we should still be facing the same way. It means that the galactic universe is finite (and Einstein even tells us how big it is). Outside it there is nothing, not even space. Light travels in what we call curved lines, and never goes outside the universe from which it originated.

The notion is of immense speculative importance.

Suppose, though, that the time dimension is also curved! Einstein does not seem to have worked out that. Perhaps the reader may see to what extraordinary speculations this may lead.

APPENDIX III

THE SUBMAXILLARY GLAND—AN INSTANCE OF ORGANIC FUNCTIONING

THREE pairs of glands open into the mouths of mammalian animals: the sublingual, submaxillary, and parotid salivary glands. Their function is to secrete saliva. Saliva consists mostly of water which contains some mineral salts, some soluble proteids, some mucin, and, in some animals, an enzyme called *ptyalin*, which has the power of dissolving starch and converting the latter into sugar. Saliva mixes with the food, so that the latter can be worked up into a "bolus," which is then swallowed; it cleans the mouth in that it removes dirt in the "spittle," and it may be a digestive ferment, or enzyme.

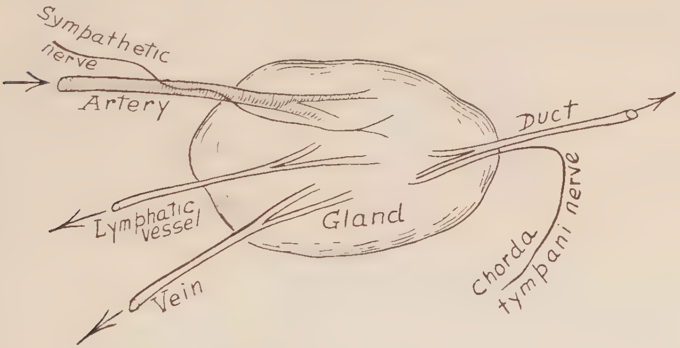

FIG. 52.—A DIAGRAM OF A SALIVARY GLAND WITH ITS VESSELS, NERVES, AND DUCT.

The gland itself consists of a very great number of alveoli which are connected with ductules, which unite to form the duct which opens into the mouth. The saliva is formed, or secreted, in the cells which constitute the walls of the alveoli. Leaving the details for a moment, note the structures connected with the gland.

An artery conveys blood to it. The latter circulates round the alveoli, and leaves the gland by means of a vein. Lymphatic vessels are also connected, and through these a watery fluid, called lymph, leaves the gland and finally enters the circulating blood of the body.

A duct leaves the gland, and through this the saliva that is secreted in the alveoli reaches the mouth.

Two nerves enter the gland. One of these comes from the medulla, and is called the chorda tympani. The other comes from the sympathetic nervous system. These are efferent nerves conveying stimuli to the gland from the central nervous system.

The duct divides into (or, rather, is formed by the union of) a great number of smaller ductules or tubes. The ends of these tubes may be thought about as swelling out to form bulbar enlargements. The walls of the ductules are thin, but those of the enlargements, or alveoli, are thick, being made up of large cells. It is in these cells that the actual formation of saliva occurs.

The artery which enters the gland divides up into a great number of smaller vessels, or arterioles, and the latter again

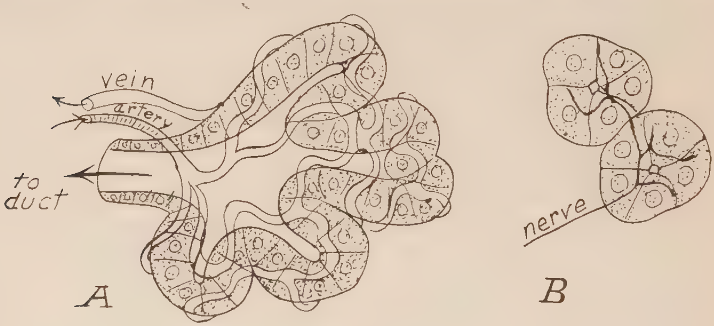

FIG. 53.

A, Diagrammatic section through an alveolus (or secreting unit) of the gland, with its capillary circulation; *B*, diagram of the terminations of a secretory nerve among the cells of an alveolus.

break up into capillaries. The capillaries are distributed over the alveoli, as shown in Fig. 53. After circulating through the capillaries, the blood leaves the gland by means of the vein.

The nerves similarly break up into smaller branches. Some of these divide further into very fine fibrils, which are distributed as a fine network over the alveoli on the outside, or even in between, the cells. Other branches of both nerves break up into fibres which end in the muscles of the walls of the artery and arterioles.

Such is the structure. How does it function ?

Generally saliva flows into the mouth when savoury food substances stimulate the gland to act. This is a reflex, and the afferent nerves are the gustatory and olfactory ones—that is, those conveying the taste and smell stimuli to the brain. But this is not all by any means, for if meat be shown to a hungry

dog there will be a reflex flow of saliva from the mouth, even though the animal does not *smell* the food. The afferent paths are now the optic nerves. But, again, this is not all, for " when the dog realises that he is being played with . . . the psychical secretion of saliva ceases." And yet again, it is said that the thought, or memory, of savoury food may cause a secretion of saliva in ourselves.

When small pebbles are put into a dog's mouth, the animal shifts them about with his tongue and then spits them out. When the same substance, crushed into sand, are put in his mouth, thin watery saliva is secreted, and the sand is washed out. So, also, with dry biscuits. When meat is put in his mouth, thick, viscid saliva is secreted.

Thus, although the secretion of saliva is a reflex, it is one that is controlled and modified (or even arrested) in a variety of ways. There is no simple, invariable, mechanical response.

How is the control effected ?

It was thought at one time that the control was effected by the change of calibre of the arterioles. The saliva comes ultimately from the blood that circulates through the gland. Now the fibres of the chorda tympani dilate the vessels and permit a more abundant flow of blood through the gland. Accordingly, there is a greater flow of saliva. The fibres of the sympathetic contract the arterioles, and so a decreased flow of blood takes place and there is a decreased flow of saliva. The inference appeared to be that the secretion of saliva was a mere filtration from the blood, and depended on the pressure of the latter—the greater the pressure, the greater the flow. But the saliva has not the same composition as the liquid part of the blood, so there is more than mere filtration to be accounted for. Further, when the gland is poisoned with atropin, the dilating action of the chorda tympani is not affected; yet when the latter nerve is stimulated in such a poisoned gland, there is no increased flow of saliva. On the other hand, when it is poisoned with pilocarpin there is an increased flow.

The explanation of these experiments is that there are secretory nerve fibres in addition to those that dilate or contract the arterioles. Poisoning these secretory fibres in one way or another affects the secretion of saliva. We see that there are nerve fibres coming into connection with the cells of the alveoli.

It is, then, these secretory nerve fibres, acting directly on the cells, that stimulate the latter to secrete the liquid. The other nerve fibres which act on the bloodvessels control the supply of

blood to the cells as the circumstances require. How do the secretory fibres act on the cells? When the latter function, it can actually be seen that granules of some material taken from the blood have been formed and deposited in their substance. The stimuli of the secretory fibres seem to cause these granules to disintegrate, absorb water, and swell, finally discharging their contents into the cavity of the alveolus. This is the thing, then, that has to be "explained."

What is the substance of the granules? How is it taken from the blood? How is it liberated into the alveolus when the cell is stimulated? How is it that the nature of the substance varies according to the kind of food? How can the sight of food produce the same effect as the taste or smell of food? How can the memory of food do the same thing as the taste of food—that is, how does an immaterial, non-energetic stimulus produce the same response as an energetic, material one?

It will be seen that what we have attained so far is a rather imperfect description of the mechanism of control of the secretion of saliva. So far as the act of secretion itself is concerned, physiology has succeeded in substituting a biochemical description for a mechanical one, but even the biochemical description involves at the present time hypotheses that have still to be verified.

INDEX

PRINTED IN GREAT BRITAIN BY
BILLING AND SONS, LTD., GUILDFORD AND ESHER